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SYSTEM FOR NUMERICALLY RATING WATER SUPPLY SYSTEMS

HITTMAN ASSOCIATES, INCORPORATED

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

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Hittman Associates, Inc.

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by

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for the
Water Supply Division
Office of Air and Water Programs
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EPA Review Notice

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ABSTRACT

A concept for numerically rating urban water supplies was developed and its feasibility was demonstrated by applying the concept to an existing water supply system. The rating concept is based upon determining the reliability of system equipment, the probability that the system furnishes water meeting federal drinking water standards, the effect of equipment failure on system water quality, and the relative ability of the system to remove constituents from raw water that exceed the drinking water standards. The rating system concept is too complex in its present form to be practical for general application in the field. The concept requires simplification and preparation of a manual for its application in the field. In developing a firm rating system, data should be analyzed to determine the probable effects of component failure on water quality, to develop a data bank of failure rate data for components, to determine and quantify effects of personnel skill levels on water quality, and to determine the effects of population, industrial environments, and legal controls on the reliability of water systems.

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SECTION I

CONCLUSIONS

1. A system for numerically rating urban water supply systems based on statistical evaluation techniques is feasible as demonstrated by this project. Because the system is too complex in its present form to be practical in the field, techniques such as computer adaptation are required to simplify the system application.

2. The probability of exceeding the constituent limits of the Public Health Service Drinking Water Standards can be defined statistically based on water quality sample test results and the probability of system failures.

3. The susceptibility of a given water system to one-time occurrences of distributing hazardous water can be predicted using reliability and failure mode effect analysis techniques.

4. The normalized numerical rating which combines water system reliability, water quality analysis, failure effects, and design adequacy on a zero to 100 scale can be considered to be directly correlated to the percentage probability that a given urban system will continuously supply water of acceptable quality. A simplified rating may be obtained by evaluating the two areas of water quality and failure effects alone; however, this approach does not consider overall system reliability and design adequacy.

5. The numerical rating system developed in this project permits comparison of the results of evaluating unit process operation, subsystem, and system and the identification of those items which influence the overall rating. This feature also permits priorities to be assigned to corrective actions to attain the highest return in water quality per dollar spent.

6. Further research and development work is required to refine the rating system in the areas of failure modes and effects; further data on reliability, maintainability, and availability; interrelationship of personnel experience, training, and certification to system performance; and the probability and consequences of cross-connections.

SECTION II

RECOMMENDATIONS

1. The application of the rating system concept in the field should be refined and simplified using automatic data processing methods.

2. A procedural type manual should be prepared to permit the urban water rating system to be generally implemented by governmental organizations and water utility management.

3. An experimental program should be conducted to provide data on the removal efficiencies of the unit processes used in water treatment under various operating conditions including possible failure modes. Data should also be collected from operating systems to better define the relationship between system failures and the quality of water.

4. The data bank of reliability, maintainability, and availability information for components used in water supply systems should be expanded and verified through the survey of more systems. Sufficient data should be collected to permit failure probabilities to be defined with respect to materials of construction, age, maintenance, and personnel skills.

5. A manual on the reliability and maintainability aspects of water supply, treatment, and distribution system design should be prepared to provide guidance in the design of new plants and modifications of existing plants.

6. In the surveys and inspections of water supply systems, data should also be collected for personnel skill levels, experience, training, and certification. An attempt should be made to correlate this information with the plant reliability and water quality data in order to establish a more concise method for rating the maintenance,operation, and surveillance aspects of water supply systems.

7. Requirements for water quality surveillance samples should include criteria for sampling and analysis for constituents where circumstances could indicate their presence, for example, particular industries in the watershed, materials used in the distribution system, cross-connection potentials. The number of samples to be taken should also be specified with criteria and methods for evaluating the statistical significance of the results.

8. Further work should be performed to better define the probability of industrial and nonindustrial cross-connections and the possible severity of such occurrences to permit a more meaningful rating.

SECTION III

INTRODUCTION

BACKGROUND

Over 1600 public water supply systems have been surveyed and evaluated in recent years to determine acceptability when compared with U.S. Public Health Service Drinking Water Standards. In addition to providing constituent limits for bacteriological, chemical, physical, and radiological contaminants, the standards require that the physical facilities, the operation, and the surveillance provided by the appropriate regulatory agency must be taken into consideration. Several guides had been developed to provide criteria for evaluating supplies such as the "Manual for Evaluation of Public Water Supplies" and "A Guide to the Interstate Carrier Water Supply Certification Program." The use of these guides required considerable judgement in interpreting the relative effects of facilities, their operation, and their surveillance on the dependability of the overall water system. It was concluded that the feasibility of developing a concept for numerically rating water supply systems should be established. The concept should combine the effects of all pertinent factors affecting water quality and determine the significance of improvement of a particular segment of the total system in terms of cost effectiveness and overall system improvement in reliability.

PURPOSE

The purpose is to determine the feasibility of developing a rating system for predicting the ability of an urban water supply system to produce water consistently meeting the constituent limits of the Federal Drinking Water Standards. The standards used in the development are the 1962 U.S. Public Health Service Drinking Water Standards.

SCOPE

The scope of the effort involves the accomplishment of three major tasks:

1. Define all physical, operational, and surveillance components of urban water systems that have, or may have, an effect on the ability of the total water supply system to produce water of a given quality.
2. Develop the concept of a numerical rating system that can be used to combine the effect of all pertinent components and produce an indication of the ability of the water supply system to consistently produce water meeting the constituent limits of the Federal Drinking Water Standards.
3. Demonstrate the application of the rating system concept by rating an existing urban water supply system.

APPROACH

The technical approach to developing the rating system utilizes the application of reliability and maintainability engineering techniques to predict the capability of the water system to consistently produce drinking water meeting the 1962 Public Health Service Drinking Water Standards. These techniques utilize statistical analysis methods to determine probabilities of successful operation and of detecting conditions outside of recommended water constituent standards. The approach involved the accomplishment of the following efforts:

1. Define the effects of physical, operational, and surveillance components on the quality of water supplied by preparing a failure modes and effects analysis which is a systematic method of defining possible types of failures and malfunctions, consequences and severity of the consequences. Develop matrices for use in evaluating water systems.

2. Develop block diagrams which show the dependency of each component and process or subsystem relative to the performance of the overall water supply system. This includes water sources and characteristics of the watershed, the treatment system, the distribution system, and the associated process analytical procedures and controls. The block diagrams show dependency of process and component operations in series and parallel networks. Include methods and definitions for developing block diagrams for a specific system from the generalized models. The block diagrams form the basis for mathematical models that numerically relate reliability of processes and components. The numerical relationships serve to identify processes and components critical to the operation of the system.

3. Evaluate surveillance techniques and provide statistical analysis procedures for determining the probability of detecting conditions outside of the standards. Considerations include number of samples taken, frequency, and variability of analytical results. Evaluate process controls in current water systems for their capability to detect undesirable conditions prior to distribution of water.

4. Develop component and process failure rates and repair times from analysis of operation and maintenance data. Collect the operation and maintenance data from existing records in water systems and other data bank sources. Prepare procedures for applying failure rate and repair time to the models to determine system reliability and maintainability. The system reliability and maintainability gives a quantitative measure of the systems ability to operate trouble-free.

5. Develop a procedure for subjectively rating the quality of maintenance and operation of a system. Considerations include training, instruction, records, experience, and schedules.

6. Develop procedures to use the reliability prediction models and analysis techniques to evaluate and rate the availability and consequences of failure of the urban water supply system.

A detailed and a composite rating system is derived. The system is also useful for identifying items in order of priority that would improve the probability of reliably producing water of acceptable quality. The detailed and composite rating procedures are given in Appendices A through I. The survey and analysis procedures generally contain the following:

1. Check-off lists are furnished to define the conditions in the watershed, treatment, and distribution that adversely affect the quality of the water.

2. Matrices for tracing the operational processes of the specific water supply system are furnished for modeling plant reliability.

3. In addition to survey sheets for evaluating maintenance and operation, definitions and analytical formulas are furnished for evaluating water system data on the number and type of failures, corrective maintenance, and preventive maintenance.

4. Tables of mean time to failures and mean time to repair for water system components are furnished for determining reliability.

5. The water quality and design adequacy of treatment is rated by its constituent removal effectiveness and ability to meet standards for water quality. Failure modes and effects for

various components, processes, and operations are included for reference.

6. Summary data sheets are furnished for presenting detailed and composite rating results.

7. An example rating of an existing water supply system is provided for guidance in preparing other ratings. The example is the result of testing the rating system concept on an existing water supply system to demonstrate feasibility and test the approach. The demonstration showed the concept to be feasible but complex and impractical for general application in the field. Changes have been made to the rating concept which were the direct result of testing the system and finding areas requiring modification.

SECTION IV

RECOMMENDED RATING PROCEDURES

RATING SYSTEM CONCEPT

Two primary study areas were pursued in developing the rating system concept: (1) Reliability of the system and (2) probability of meeting the constituent limits of federal water quality standards. Two secondary study areas evolved from the primaries as part of the rating system concept: (3) probable effect on the water system of unit process operation failure and (4) the design adequacy of the system. The four rating areas were considered most important as a result of performing a failure modes and effects analysis which defines physical, operational, and surveillance components that have effects on the water quality (Appendix I). The four rating areas are defined below in general terms and are explained in greater detail in subsequent paragraphs and the appendices.

1. Water System Reliability - The probability that the water system will perform its intended design function without failure as required on a continuous basis.
2. Water Quality Analysis - The probability, based on historical records, that the distributed water meets the constituent limits of the drinking water standard.
3. Failure Effects Analysis - An analysis of the probable effect of failure of unit operations or subsystems on the quality of distributed water.
4. Design Adequacy - The designed ability of the water system measured as a relative value of the probability of distributed water meeting the constituent limits of the drinking water standard in relation to the probability of the raw water source exceeding the constituent limits.

Statistical data are evaluated and used with models and techniques to provide quantitative results for water system reliability, water quality, and design adequacy analyses. Subjective and quantitative evaluations are

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used in the failure effects analysis. An averaging procedure is used to combine the four areas into a single composite rating. Water systems were subdivided into subsystems and unit operations to facilitate an organized approach to system modeling and analysis. The subsystem structure and identification numbers are:

11	Obtain raw water
12	Treat raw water
13	Distribute treated water
14	Provide water quality surveillance
15	Provide services

The subsystems are subdivided into functions, subfunctions, and unit operations having identifying numbers beginning with the subsystem number. The subsystem matrices are shown in Appendices C, D, E, F, and G for each subsystem.

WATER SYSTEM RELIABILITY

Reliability in a water system is the probability that it is satisfactorily performing its intended design function as required on a continuous basis. The evaluation of system reliability requires modeling and following the procedural steps described in Appendix A. Separate relibility models are used to evaluate and develop ratings for each subsystem. For each subsystem, a structure and matrix (see Appendices, Figures C-1, D-1, E-1, F-1, and G-1), unit operation reliability (Table A-1) sheets, and subsystem reliability (Table A-2) sheets are prepared. Component reliability data compiled on Table A-2 is then used to calculate the reliability of the subsystems. The system rating is obtained as the ratio of the actual estimated system reliability to the highest possible evaluated reliability. The reliability rating computations are included for the demonstration system in Appendices C, D, E, F, and G.

WATER QUALITY ANALYSIS

The water quality analysis measures the probability that a water supply system is furnishing water meeting the drinking water standards. The evaluation procedures are given in Appendix B. Water sample test data are statistically analyzed to determine the probability of exceeding the drinking water standards for bacteriological, chemical, physical, and radiological constituents. The probabilities are weighted for each constituent grouping based on the failure effects analysis. The average of the weighted probabilities is the water quality surveillance rating for the water system. The procedures are illustrated for the demonstration system in Appendices C, D, E, F, and G.

FAILURE EFFECTS ANALYSIS

A failure modes and effects analysis was prepared for each unit operation to define physical, operational, and surveillance components that have, or may have, an effect on the ability of the water supply system to meet drinking water standards. In formal reliability evaluations where failure mode and effect data are collected, the reliability modeling and analysis consider only the occurrence of failure modes that have detrimental effects on the satisfactory performance of the system. Unit operation failure modes could not be correlated with effects on water quality using the component reliability data available from the water systems studied; therefore, a rating of weighted probable effects was developed for use with the reliability analysis to obtain a failure effect rating. The failure effect rating is a relative effect for each operation which assigns higher weight to critical operations (those having highest effect on system) and less weight to less critical operations. The failure effects analysis and rating combines the probable effect of unit operation failure on the system with the reliability of the unit operation; this rates the probability that the effect will not occur. Table A-5 of Appendix A illustrates the computation of the failure effect rating for operations; the table is filled in for the demonstration system.

DESIGN ADEQUACY

The design adequacy rating is a comparison of raw to treated to distributed water to note relative improvement in water quality. Design adequacy is the ability to remove constituents from raw water in order to obtain water meeting drinking water standards. The procedures are given in Appendix B. The weighted probability of exceeding the drinking water standards is calculated for the raw water source, the treated water, and the distributed water. The design adequacy is calculated by comparing:

1. Treated water with raw water for design adequacy of the treatment subsystem
2. Distributed water with treated water for design adequacy of the distribution subsystem
3. Distributed water with raw water for design adequacy of the water supply system

The procedures are illustrated for the demonstration system in Appendix B.

COMPOSITE RATING

The composite rating is an average of four ratings: water system reliability, water quality analysis, failure effects analysis, and design adequacy. The resultant rating is a score between 0 and 100, with 100 being the highest attainable score. Relative ratings for subsystems, operations, and components with respect to the system rating is a measure of subsystem, operation, and component criticality to the ability of the water supply system to meet the constituent limits of the drinking water standards. The procedures for calculating the system rating and methods for identifying critical areas in the water system are given in Appendix H. Critical areas are those operations which are primarily responsible for low rating results.

The demonstration system composite rating is given in Appendix H. Calculation of critical subsystems, operations, and components critical to reliability are given in Appendix H. Criticality with respect to failure effects, water quality, and design adequacy are given in the results, Section V.

A simplified system composite rating may be obtained by only averaging the water quality analysis rating and the failure effects rating. The result would not include a rating of overall system reliability and design adequacy; however, reliability is incorporated in evaluating failure effects of unit operations and distributed water quality is measured in the water quality analysis. The simplified rating would have some measures of reliability and design adequacy even though overall system reliability and design adequacy would be excluded. Exclusion of overall system reliability would leave out the rating of probability of system failure. Exclusion of system design adequacy would leave out a relative measure of the ability of the system to treat and distribute quality water relative to raw water source quality.

WATER SYSTEM SURVEY

The evaluation of a public drinking water supply appraises the water source and subsequent treatment, distribution, and storage with respect to bacteriological, chemical, physical, and radiological constituents of the water and evaluates system operation, surveillance, and control.[1] Its purpose is to obtain the information required to evaluate the ability of the water supply system to consistently furnish water meeting the Federal Drinking Water Standards. The survey involves determining the character of the raw water, raw water quality, required treatment, reliability of the treatment process, distribution of water, reliability of the distribution system, the distributed water quality, and design adequacy of the system. The survey involves a visit to the system and a complete survey of the entire system, that is, from source to consumer. This survey is performed to model system processes for reliability prediction and to determine if potential hazards to water quality exist such as cross-connections, common walls, source contamination, and any other possible contamination of finished and distributed water. The survey also considers the ability of the system to furnish sufficient quantity to meet system demand for water. The completed survey contains an evaluation and rating of the following basic data.[1]

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[1] Superscripts identify references on page 41.

1. A review of office records and system management and planning to obtain data for:
    - (a) Bacterial records for 12 months and chemical records on water from the source, the treatment plant, and the distribution system
    - (b) Operating records showing present capacity, water demands, and production to meet demands
    - (c) Special reports and studies showing anticipated future demands.
    - (d) State and local regulations and plumbing codes pertaining to water systems
2. A sanitary survey of the entire system to provide data including:
    - (a) Physical features of the water system including adequacy of supply, treatment processes and equipment, storage facilities, and delivery capabilities
    - (b) Management and operation methods and of the training, experience, and capabilities of personnel
    - (c) Treatment plant and supporting laboratory equipment and procedures including the qualification of the laboratory personnel

After performing the survey, the results of the examination are quantified to provide a numerical rating of the ability of the system to consistently produce water meeting the Federal Drinking Water Standards. The standards used in the program are the "Public Health Service Drinking Water Standards, Revised 1962,"[2] These standards set forth recommended and mandatory constituent limits and criteria for water supply systems operation, maintenance, and health survey. The quantitative standards are included in the rating system.

The survey portion of the rating system is divided into five parts which correspond to the subsystem structure which was developed in this project for water supply systems. The five parts are:

11	Obtain raw water
12	Treat raw water
13	Distribute treated water
14	Provide water quality surveillance
15	Provide services

The data collected for each of the subsystems is described in the following paragraphs and Appendices C, D, E, F, and G. The procedures for surveying and rating a water system were tested and demonstrated on a water supply system that serves a city of 24,000 people, and the procedures and forms in the appendices include this information to illustrate the use of the system.

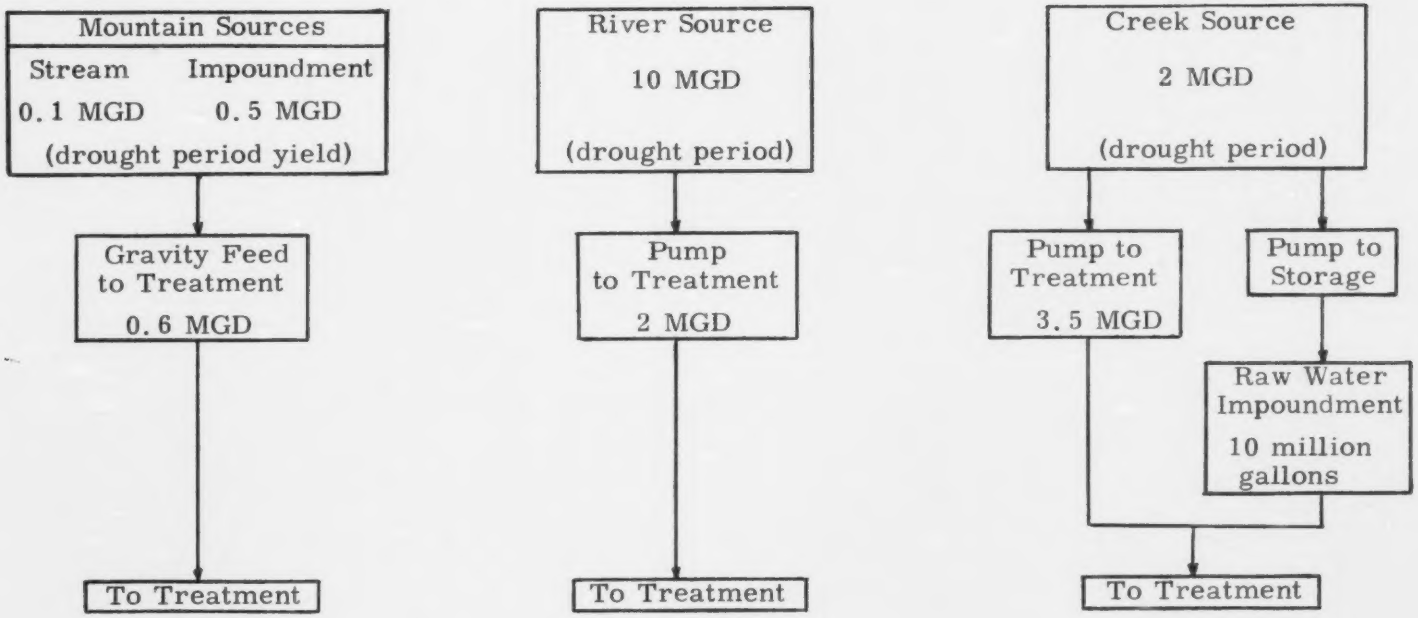
Obtain Raw Water, Subsystem 11. The raw water source subsystem includes the source and all equipment used to obtain and convey the water to treatment (or to distribution if no treatment is performed). The source or sources used for obtaining water are surveyed to determine the reliability and adequacy of the source to meet quality requirements and to meet demand. The quality of the raw water dictates the required treatment processes to insure a safe drinking water is provided to consumers. The yield of the source determines the ability to satisfy demands. Detailed survey considerations and procedures involve determining: (1) minimum safe daily drought period yield, (2) demand over past five years, (3) estimated demand five years into the future, (4) the reliability of the sources and intake, and (5) the probability of exceeding the constituent limits of the DWS in the source. Source failure modes are given in Appendix I in the failure modes and effects analysis for subsystem 11.

The demonstration system has four sources: a mountain impoundment, mountain stream, river source, and a creek. The mountain sources flow by gravity to the city and have partially controlled watersheds in that the city owns the watershed but allows public access to the watershed. The river and creek sources are located in the valley, are subject to farm and dairy pollution, and have intakes and pumps to convey the water to treatment. The creek source also utilizes a 10 million gallon raw water reservoir for use as a source during heavy demand periods and when turbidity in the creek becomes excessive and creates treatment problems. A process flow diagram for the source is shown in Figure 1. The results of the survey, modeling, and raw water quality evaluation are given in Appendix C.

Treat Raw Water, Subsystem 12. Treatment of water includes all chemical and physical processes required to prepare water for consumption by the public. Processes vary from simple disinfection for high quality sources (less than 100 coliform/100 m) to complete conventional treatment for less desirable sources involving presedimentation, predisinfection, coagulation and flocculation, sedimentation, filtration, and post disinfection. The treatment subsystem includes the necessary operations and components to reliably remove constituents which exceed the drinking water standards and to treat sufficient water to meet the consumer demands. Appendix B includes the checklist, subsystem structure, and failure modes and effects analysis for surveying and modeling the water treatment subsystem.

The demonstration system process flow diagram for raw water treatment is shown in Figure 2. The gravity-fed mountain sources are chlorinated, fluoridated, ammoniated, and treated with lime (lime to maintain proper pH). The river and creek sources receive complete conventional treatment. At the time of the survey, water was being distributed following treatment at the following flows:

Mountain sources	0.6 MGD
River source	1.0 MGD
Creek source	2.0 MGD


Mountain Sources
Stream
Impoundment
0.1 MGD
0.5 MGD
(drought period yield)
Gravity Feed to Treatment
0.6 MGD
To Treatment
River Source
10 MGD
(drought period)
Pump to Treatment
2 MGD
To Treatment
Creek Source
2 MGD
(drought period)
Pump to Treatment
3.5 MGD
Pump to Storage
Raw Water Impoundment
10 million gallons
To Treatment

Total drought source yield = 12.6 MGD

NOTE: In an emergency, a special connection can be made to a nearby military installation to obtain about 2 MGD of treated water from the river source. This is not included since the pipe connection was not installed because it is an emergency source, cannot be simply turned on, and is not a part of the continuous supply.

Figure 1. Demonstration System Raw Water Source Process Flow

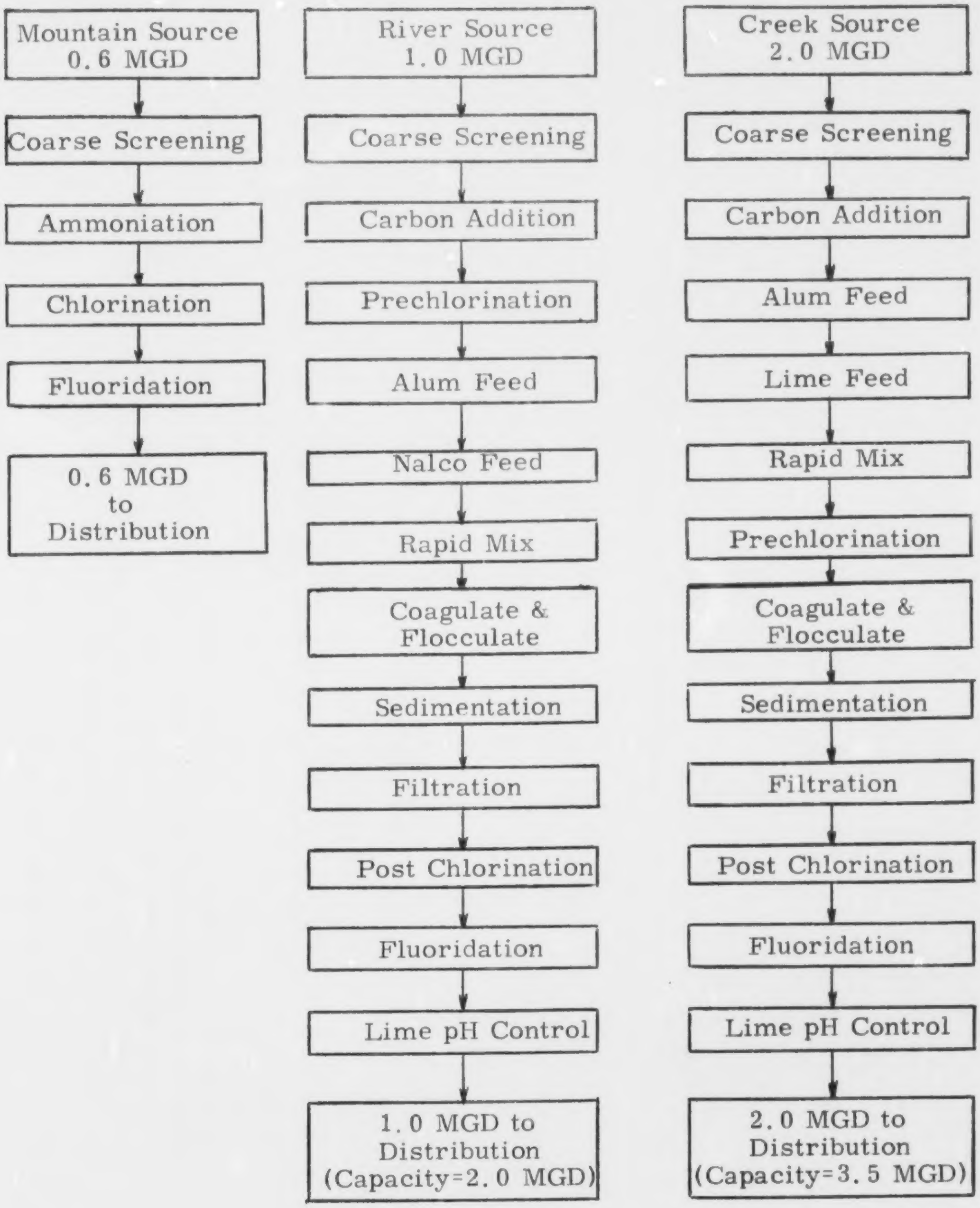

Mountain Source 0.6 MGD
Coarse Screening
Ammoniation
Chlorination
Fluoridation
0.6 MGD to Distribution
River Source 1.0 MGD
Coarse Screening
Carbon Addition
Prechlorination
Alum Feed
Nalco Feed
Rapid Mix
Coagulate & Flocculate
Sedimentation
Filtration
Post Chlorination
Fluoridation
Lime pH Control
1.0 MGD to Distribution (Capacity=2.0 MGD)
Creek Source 2.0 MGD
Coarse Screening
Carbon Addition
Alum Feed
Lime Feed
Rapid Mix
Prechlorination
Coagulate & Flocculate
Sedimentation
Filtration
Post Chlorination
Fluoridation
Lime pH Control
2.0 MGD to Distribution (Capacity=3.5 MGD)

Figure 2. Demonstration System Raw Water Treatment Process Flow

The results of the survey, modeling, and treated water quality evaluation are given in Appendix D for raw water treatment.

Distribute Treated Water, Subsystem 13. The distribution of treated water includes all components required to store and convey water to the consumers without degrading the water quality and to meet the demanded flow rate. The required flow rate must be met in order to avoid low system pressure and possible contamination by back pressures or cross-connections. The components making up the system include pipe mains, pumps, storage tanks and reservoirs, valves, and fire hydrants. Chlorination and pH control are used in large systems to maintain chlorine residual (disinfection) and control corrosiveness of water. The survey checklist, subsystem modeling structure, rating procedures, and failure modes and effects analysis are given in Appendix E for the distribution subsystem.

The demonstration system process flow diagram for the distribution subsystem is shown in Figure 3. The mountain sources gravity feed treated water to the system. The treated river and creek water is fed to distribution by high-lift pumps. The distribution system contains pipe mains, valves, hydrants, and two elevated tanks. The survey results, modeling, and water quality evaluation are given in Appendix E for the distribution subsystem.

Provide Water Quality Surveillance, Subsystem 14. Water quality surveillance is the sampling and analyzing of distributed water to predict that it is within the limits of the drinking water standards. Other tests are also performed to efficiently control the treatment of raw water. To insure adequate analytical controls and results, the laboratory procedures must conform to the Standard Methods for the Examination of Water and Wastewater.[3] The analyses should be performed by qualified chemists or laboratory technicians using proper equipment. The checklist and failure modes and effects analysis in Appendix F are used to guide the evaluation when making the rating. If other laboratories perform analyses in addition to the local laboratory, the results should

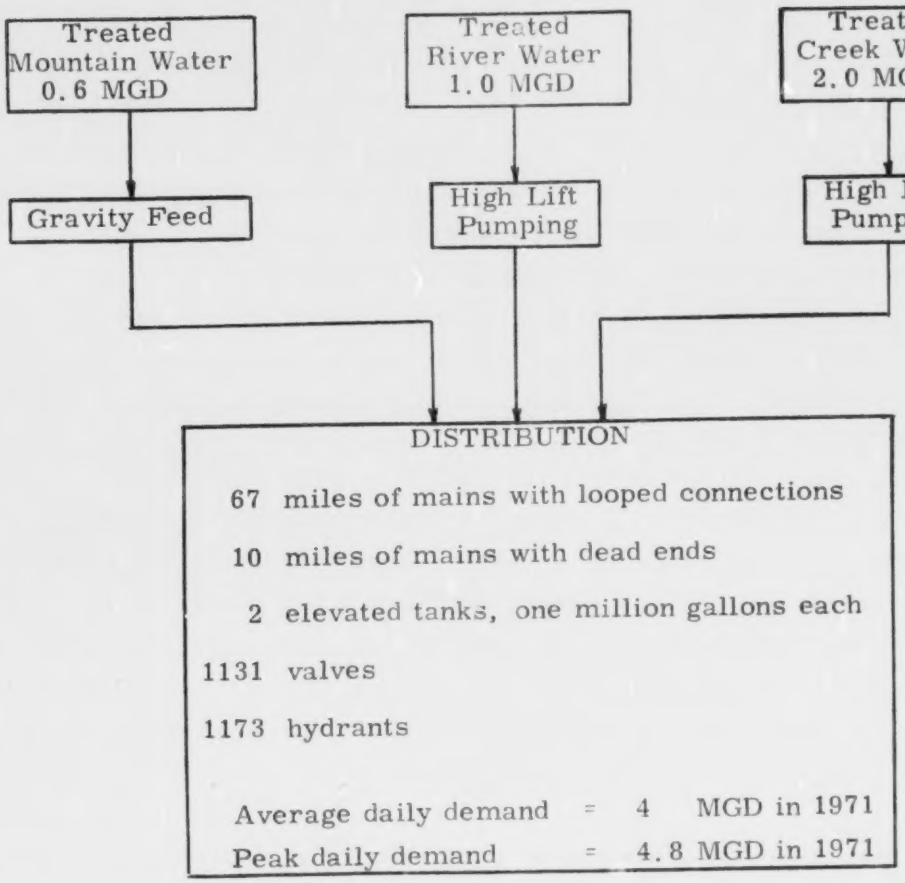

Treated Mountain Water 0.6 MGD
Treated River Water 1.0 MGD
Treated Creek Water 2.0 MGD
Gravity Feed
High Lift Pumping
High Lift Pumping
DISTRIBUTION
67 miles of mains with looped connections
10 miles of mains with dead ends
2 elevated tanks, one million gallons each
1131 valves
1173 hydrants
Average daily demand = 4 MGD in 1971
Peak daily demand = 4.8 MGD in 1971

Figure 3. Demonstration System Distributed Water Process Flow

be compared; should significant differences exist and water of questionable quality is being distributed, considerable weight should be given to evaluating the cause of these differences when making the rating.

The evaluation of the demonstration system is given in Appendix F for the water quality surveillance subsystem.

Provide Services, Subsystem 15. Providing services includes personnel, utilities, and control equipment. Adequate electric power, heat, sanitary facilities, human engineering, maintenance, operation, and control operations are essential to the ability to consistently furnish quality water. Proper preventive maintenance programs should be used to prevent component failure. Corrective maintenance should be efficiently performed to insure system reliability is maintained at a high level and not allowed to degrade. The rating of equipment is quantitative. The rating of personnel and personnel services is subjective. The checklist for evaluating the subsystem is given in Appendix G. Appendix G is filled in for the demonstration system.

RATING SYSTEM DEMONSTRATION EFFORT

As previously stated, the rating concept was tested and demonstrated in an existing water system. The survey was performed in two days by three engineers, two of whom were not familiar with the development of the procedures and the other the primary developer of the procedures. An additional 80 man-hours were required to complete the rating following the survey. Several procedure revisions were required during the analysis of survey results in order to attain more meaningful results. The normalization of results was the major revision which allows results from different systems to be compared regardless of system design differences in treatment and complexity. The revisions have been included in the rating procedures of Appendices A through H.

SECTION V

RESULTS

CONCEPT DEMONSTRATION

The concept does provide a numerical rating of the ability of the water supply system to consistently supply water meeting the constituent limits of the drinking water standards. The results of the concept demonstration are a numerical rating of 78 out of a possible 100. This rating is made up as follows:

Water system reliability rating	=	0.54
Water quality rating	=	0.84
Failure effects rating	=	0.90
Design adequacy rating	=	0.85
Average	=	0.78

The results of each rating are discussed in the following paragraphs.

Water System Reliability Rating. The demonstration system reliability reflects equipment reliability. The equipment reliability for the demonstration system is 0.51 out of a possible maximum reliability of 0.96. The 0.54 rating is obtained by dividing the actual reliability of 0.51 by the maximum possible reliability of 0.96. Critical operations, or those having less than a 0.99 reliability, are:

Mountain impoundment water ammoniation and chlorination	R = 0.984
Mountain stream water ammoniation and chlorination	R = 0.983
Creek water chemical feed, rapid mix, coagulation, flocculation, sedimentation	R = 0.986
Creek water filtration	R = 0.985

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River water chemical feed, rapid mix, coagulation, flocculation, sedimentation	R = 0.965
River water filtration	R = 0.973
Convey treated water	R = 0.704
Monitoring equipment	R = 0.959

Other items which are potentially hazardous to the system reliability are listed below. These items may or may never affect water quality, but in the event of a particular series of equipment failures, a hazardous condition could develop.

1. Water chlorinators in all locations must be taken out of service in order to change bottles. Proper valving on a manifold should be installed in order that a replacement bottle can be turned on to supply chlorine while the empty bottle is removed.

2. Deicing protection of sedimentation basins uses water from the distribution mains. An antisiphon or vacuum-breaker valve should be placed in the line to prevent back flow should distribution main pressure ever drop.

3. Chemical feeders use water from the distribution main for mixing slurries. All mixers had the water supply line immersed in the slurry and a cross-connection might occur should raw water back up through chemical feed lines. An air gap should be provided between water main feed and slurry in the chemical slurry mixers or a vacuum-breaker valve should be installed in the water line.

Water Quality Rating. The water quality rating is based on the results of the water system laboratory and state health department laboratory results. The tests performed are for bacteria concentration, chemical constituent concentration, and physical characteristics.

1. Bacteriological examination; 10 mℓ portions

   (a) Probability of coliform positives in more than five percent of samples when 20 or more are examined per month

   (b) Probability of presence of coliform group in three or more 10 mℓ portions of a standard sample

   (c) For population of 24,000 people, 30 samples are required per month. The demonstration system is sampled 52 times per month from the distribution system.

   (d) Probability of exceeding the drinking water standard for coliform = 0 + 0.0032 = 0.0032

   (e) Probability of not exceeding the drinking water standard for coliform = 1 - 0.0032 = 0.9968

2. Chemical constituent examination

   (a) Mandatory constituents, other than fluoride, are not tested. The measurement of fluoride content in the distribution water is analyzed.

   Probability of fluoride less than 0.9 mg/ℓ = 0.64

   Probability of fluoride greater than 1.7 mg/ℓ = 0

   Probability of fluoride greater than 0.9 mg/ℓ and less than 1.7 mg/ℓ
   = 1 - (0.64 + 0) = 0.36

   Since low fluoride content is not a hazard to health, the probability of creating a health hazard is 0; however, low fluoride content does not provide the benefits of fluoridation to dental health.

Lead content is not analyzed. Lead is used to make up service (customer) connections in the demonstration system. The pH of the water becomes critical in insuring that lead is not dissolved into the water. From state tests, the pH averages 7.4 in 100 samples taken monthly over a two-year period. The pH range was 5.5 to 9.0 and the standard deviation was 0.3. The American Water Works Association recommends that water pH should fall in the range of 5.6 to 9.5. The probability that the pH is in the range is 0.9984. Since the average or mean pH is 7.4, which is above neutrality, the pH is considered satisfactory and lead should not be dissolved into the water in amounts hazardous to health; however, lead content should be analyzed at the customers' taps to assure that lead is not a hazard.

(b) Recommended constituents in the distributed water are tested to a very limited degree by the city water utility and the state. Iron, copper, and total dissolved solids are tested in distributed water. Sulfate and chlorides are periodically tested in the raw water and are not a problem. The watersheds consist primarily of agricultural and dairy farming; therefore, nitrates should be tested and are not. Accepting recommended limits based on the Fe, Cu, and TDS analyses, the probabilities of not exceeding recommended constituent limits are listed below.

Probability of iron of 0.3 mg/ℓ or less = 0.39

Probability of copper of 1.0 mg/ℓ or less = 0.67

Probability of TDS of 500 mg/ℓ or less = 1.00

Probability of distributed water having constituents content less than recommended limits = 0.39 x 0.67 x 1.00 = 0.26

(c) Physical characteristics are tested. Turbidity and color are routinely tested. Taste and odors are tested when reported by the customer.

Probability of turbidity of 5 or less units = 0.93

Probability of color of 15 or less units = 0.79

Probability of distributed water having physical characteristics less than drinking water standards limits = 0.93 x 0.79 = 0.73

From the analysis, the low water quality rating is primarily due to chemical and physical characteristics of the distributed water. Analysis is not made of iron and copper content of water immediately following treatment; therefore, the cause of high iron and copper cannot be determined. The state found an average of 0.055 mg/ℓ of iron in the mountain source and 0.28 mg/ℓ of iron in the creek source; the river source has not been tested. Iron distribution mains are used and the combination of corrosion and iron in the source is probably the cause of high iron content. Copper content probably occurs from the corrosion of customer piping. Turbidity and color should be controlled by the treatment processes. Proper chemical mixing, coagulation, and flocculation should remove turbidity. An evaluation of laboratory tests shows that the treatment facilities routinely perform jar tests every shift; if turbidity increases due to rainstorms, tests are continuously performed. The mountain sources average turbidity is 5.5 units and treatment is not provided. The river and creek sources average 32 units of turbidity. Adequate treatment is available for the river and creek sources, but careful process control is required. The mountain sources do not appear to allow sufficient chlorine contact time prior to consumption.

Failure Effects Rating. The failure effect rating is used to evaluate the effect of operation failures on the system water quality and ability to supply water. It is used since equipment failure modes and effects on water quality could not be correlated from the survey or from the reliability data collected. Critical failure effects in the demonstration system are operations having ratings of less than 0.99 and are listed below:

Mountain impoundment water ammoniation and chlorination	Rating = 0.98
Mountain stream water ammoniation and chlorination	Rating = 0.98
River water chemical addition, rapid mix, coagulation and flocculation	Rating = 0.97
River water filtration	Rating = 0.97
Convey treated water	Rating = 0.70
Test for chemical constituent content	Rating = 0.20
Test for physical characteristics	Rating = 0.37
Test for radioactivity and control of treatment	Rating = 0.24
Habitability items	Rating = 0.98
Perform preventive maintenance	Rating = 0.85
Perform corrective maintenance	Rating = 0.85
Monitoring equipment	Rating = 0.96
Operating schedule	Rating = 0.77
Operating labor	Rating = 0.85
Operating instructions	Rating = 0.76
Raw water intake immunity to environmental problems	Rating = 0.78
Reliability of source control	Rating = 0.25
Cross-connection program	Rating = 0.37
Distribution system valve maintenance	Rating = 0.96
Laboratory reliability	Rating = 0.85
Safety equipment	Rating = 0.74

The operations having the lowest ratings are in the water quality surveillance and the services subsystems. If water analyses covered more constituents, the surveillance rating would improve. Better source controls, particularly for the mountain sources, would increase reliability of source control. Preparation and use of schedules, procedures, and manuals for preventive maintenance, corrective maintenance, and system operation, plus the addition of better safety equipment would increase the services subsystem rating.

Design Adequacy Rating. The system design adequacy rating is a measure of the degree of relative improvement in water quality due to the designed treatment processes. Three comparisons are made of the probability of not exceeding the drinking water standards. The distributed water is compared to treated water (immediately following treatment) and to raw water. Treated water is compared to raw water. The distributed water to raw water comparison gives the design adequacy rating for the system. In the demonstration system, water analyses are only performed for fluoride and pH content immediately following treatment. The only design adequacy calculation possible is for the distributed water to raw water which gives the system design adequacy of 0.85 out of a possible 1.00.

RATING CONCEPT SENSITIVITY

A measure of the rating system sensitivity to water supply system modifications is desirable in order to facilitate identification of water system modifications which would most improve the rating of the water supply system. In the rating system concept, an equipment modification or design alteration might improve more than one aspect of the rating. For example, providing redundant chlorinators might increase the reliability, the water quality rating, the design adequacy, and the failure effect rating. By providing standby chlorinators at all present chlorinator stations in the demonstration system, the reliability rating increases but the system rating does not improve (shown on the following page).

	New Rating	Old Rating
System reliability rating	0.55	0.54
Water quality rating	0.84	0.84
Failure effect rating	0.90	0.90
Design adequacy rating	0.85	0.85
	3.14	3.13
System rating average	0.78	0.78

The rating result is the same as previously obtained for the demonstration system. The change in this case is very small because the chlorinator reliability is very high. A larger effect on the rating could be attained by carefully controlling chemical feeding, mixing, coagulation and flocculation, sedimentation, filtration, and pH control in the demonstration system. Assuming this is done, the iron, copper, turbidity, and color constituents should more closely meet the drinking water standards and the water quality, failure effect, and design adequacy ratings would improve. The probability of not exceeding the drinking water standards for the four constituents is assumed to increase to at least 0.95 each for the purpose of this analysis. The increases would change the ratings as follows:

	New Rating	Old Rating
Reliability rating	0.54	0.54
Water quality rating	0.98	0.84
Failure effect rating	0.92	0.90
Design adequacy rating	0.98	0.85
	3.42	3.13
System rating average	0.85	0.78

The rating shows a significant increase from 78 to 85 if the system is carefully controlled.

The above analyses show that the rating system is sensitive to changes within a water supply system. The equipment in the demonstration system are reliable based upon data collected and used in the development of the rating concept. Adding redundant equipment does not significantly increase the reliability rating of the system. Significant changes in the rating would result if better control and surveillance of the system were practiced.

SECTION VI

DISCUSSION

RATING SYSTEM CONCEPT

The concept will provide a numerical rating of the ability of a water supply system to consistently supply water meeting the constituent limits of the drinking water standards. The development of a final rating method from the concept should include data collection and analysis to verify assumptions used in the concept:

1. Failure modes of equipment should be correlated to probable effect on unit operation and system water quality. Some failure modes affect water quality and others do not. The data collected in this program from three water systems did not have failure effects described with records of equipment failure. Specific identification of failure modes and effects will make surveys more precise and require less time to rate the system.

2. The equipment reliability data used in the concept in most cases are estimates based upon scattered records and discussions with personnel at three water systems. These data could not be verified. For a final rating system, the data should be verified and updated as systems are rated in order that the reliability history for components can be compiled for failure probabilities with respect to materials of construction, age, maintenance, personnel skills, and probable effect on water system.

3. Some of the survey areas require subjective ratings such as the laboratory, personnel, intake protection, and other evaluations. To provide a more precise rating of these areas, the effects on quality of water must be determined for personnel skills, environmental considerations (type

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of industry, control of watershed), and legal controls. Personnel skill levels with relation to experience, training, and certification should be related to system operation, reliability, and ability to meet drinking water standards in order to develop a concise rating for maintenance, operation, and quality surveillance.

4. Critical areas such as cross-connection and back flow potentials should be evaluated with respect to probability of occurrence and severeness of failure as a function of the industrial and other urban characteristics of the water supply system.

RATING SYSTEM CONCEPT APPLICATION AND FEASIBILITY

The concept is complex and requires considerable time and effort to obtain a rating. The demonstration of the concept required three engineers for two days to survey the water system and an additional 80 man-hours to complete the rating for a total of about 128 man-hours. This was the first application of the concept and several revisions had to be made to accomplish the rating. The water system which was rated is more complex than the average water system which would be rated when compared with the systems evaluated in the "Community Water Supply Study."[10] As reliability and failure mode and effects data are collected and verified, some areas of the survey procedures may become less critical to the rating and be deleted. For example, where equipment have standbys in reserve and adequate maintenance performed, the equipment reliability rating will very nearly equal the maximum value of 1.00. This can be seen by looking at the reliability figures in Figure A-2, Appendix A, under the reliability columns where standbys are included. In such a case, only those factors indirectly associated with reliability would need surveying and modeling such as failures which cause cross-connections or back flows to occur or failures in control of water shed which allow pollution of raw water source beyond the treatment removal capability. Another method of reducing application costs is development and use of automated data processing equipment to perform all calculations for the rating; preprinted cards could be used for survey work followed directly by keypunch, input, and calculation of results.

A simplified rating may be obtained by considering the water quality and failure effects analyses only since these incorporate the probability of exceeding constituent limits of the standards and the reliability of operations. Instead of the 0.78 rating (page 25) the demonstration system rating would become 0.87 as follows:

Water quality rating = 0.84
Failure effects rating = 0.90
Average = 0.87

This approach does not include an analysis of overall water system reliability or an evaluation of system design adequacy. Depending upon personal preference, the design adequacy rating may or may not be important; however, it is a relative measure of the ability of a water system to cope with its raw water source and supply quality water to the consumer. Overall system reliability is the probability that the system is capable of satisfactory operation at any time and this is important; however, it adds complexity to the rating procedure for modeling and calculating the water system reliability rating.

SECTION VII

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Washington, D.C.

Department of Public Utilities
Frederick, Maryland

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SECTION VIII

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SECTION X

APPENDICES

A. Water System Reliability Analysis

B. Water Quality Analysis

C. Survey of Raw Water Source

D. Survey of Raw Water Treatment

E. Survey of Treated Water Distribution

F. Survey of Water Quality Surveillance

G. Survey of System Services

H. Water System Composite Rating and Determination of Critical Operations and Components

I. Water System Failure Modes and Effects Analysis

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APPENDIX A

WATER SYSTEM RELIABILITY ANALYSIS

DEFINITIONS

Reliability is the conditional probability that at a given confidence level, equipment will perform intended functions satisfactorily for a specified length of time when used in the manner and for the purpose intended while operating under the specified environment and specified stress conditions. Reliability is a function of system design, the choice of reliable components, and the performance of required maintenance. System design is reflected in the use of standby equipment or the installation of considerable excess capacity to allow repairs to be made and the system to continue operation. Reliable components are selected based upon previous experience with similar components or by evaluating the operating history of a component to determine its reliability. The performance of required maintenance is reflected by repair (corrective) and routine (preventive) maintenance of the components and the maintainability of the component. Maintainability is a characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time when the maintenance is performed in accordance with prescribed procedures and resources.

Water systems must operate on a continuous basis to meet water demands. The system is made up of operations (unit processes) which must operate satisfactorily to achieve satisfactory operation of the system. The reliability of an operation in a water system is the probability that it is satisfactorily performing its intended design function as required on a continuous basis. The reliability is then equal to the fraction of total time that the operation is being performed or is capable of being performed. Two terms are used in calculating this reliability:

MTBF = mean time between failures

MTTR = mean time to repair

The MTBF is the total accumulated operating hours divided by the number of failures:

$$\text{MTBF} = \frac{t}{r}$$

where:

t = accumulated operating hours

r = number of failures in time t

The MTTR is the total repair hours divided by the number of repairs:

$$\text{MTTR} = \frac{T_r}{r}$$

where:

T_r = total elapsed repair time for r repairs

r = number of failures (or repairs)

Since a water system operation must continuously operate, its reliability as previously stated becomes its operating time divided by total time required:

$$R = \frac{t}{\text{total time}}$$

where:

R = reliability

t = operating hours

total time = total time in hours the operation is required whether operating or not

Since operations perform continuously or should be available on a continuous basis, the operating time t is equal to the MTBF and the total time is equal to the MTBF plus the MTTR; that is, operating time plus downtime equals total time. On this basis, the reliability becomes:

$$R = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

This can be verified by substituting the equations for MTBF and MTTR into the reliability equation:

$$R = \frac{\frac{t}{r}}{\frac{t}{r} + \frac{T_r}{r}} = \frac{t}{t + T_r} = \frac{\text{operating time}}{\text{total time}}$$

Additional information on reliability and maintainability theory is available from References 4 through 8. If both sides of the reliability equation are divided by the MTTR, the following function is obtained:

$$R = \frac{\frac{MTBF}{MTTR}}{\frac{MTBF}{MTTR} + 1}$$

This is a useful form since the ratio of MTBF to MTTR can be used to graphically display the reliability of any single operation or component. The above equation expresses the steady state inherent reliability of a single unit. (Reliability of steady state operating units is considered synonymous with availability and it is called reliability throughout this report.) For standby situations where one unit out of two is required in order for satisfactory operation to be achieved, the reliability equation is:[4]

$$R = \frac{2(MTBF)^2 + 2(MTTR)(MTBF)}{2(MTBF)^2 + 2(MTTR)(MTBF) + (MTTR)^2}$$

For standby situations where one unit out of three is required in order to achieve satisfactory operation, the reliability equation is:

$$R = \frac{6(MTBF)^3 + 6(MTTR)(MTBF)^2 + 3(MTTR)^2(MTBF)}{6(MTBF)^3 + 6(MTTR)(MTBF)^2 + 3(MTTR)^2(MTBF) + (MTTR)^3}$$

From data collected for components in water systems, the MTBF and MTTR are such that if one of four units is required, the reliability is very close to one.

By using the ratio of MTBF to MTTR, a useful graphical solution can be developed for all models involving redundancy, steady state operation, and multiple repair capability. The solution is shown in Figure A-1. It is useful because unique components may require unit modeling and solution such as a one-of-a-kind device. The MTBF and MTTR are determined from historical operating records, the ratio of MTBF to MTTR is calculated, and, depending upon the redundancy in the design, the reliability can be read directly from Figure A-1. This is the inherent reliability of the unit and considers only failures to the unit. Another measure of reliability and availability is the achieved reliability which includes preventive maintenance events and time as well as failures and corrective maintenance times. The terms used to describe achieved reliability are:

MTBM = mean time between maintenance

$$\text{MTBM} = \frac{t}{r + p}$$

where:

t = operating time

r = number of failures in time t

p = number of preventive maintenance events in time t

MTTM = mean time to maintain

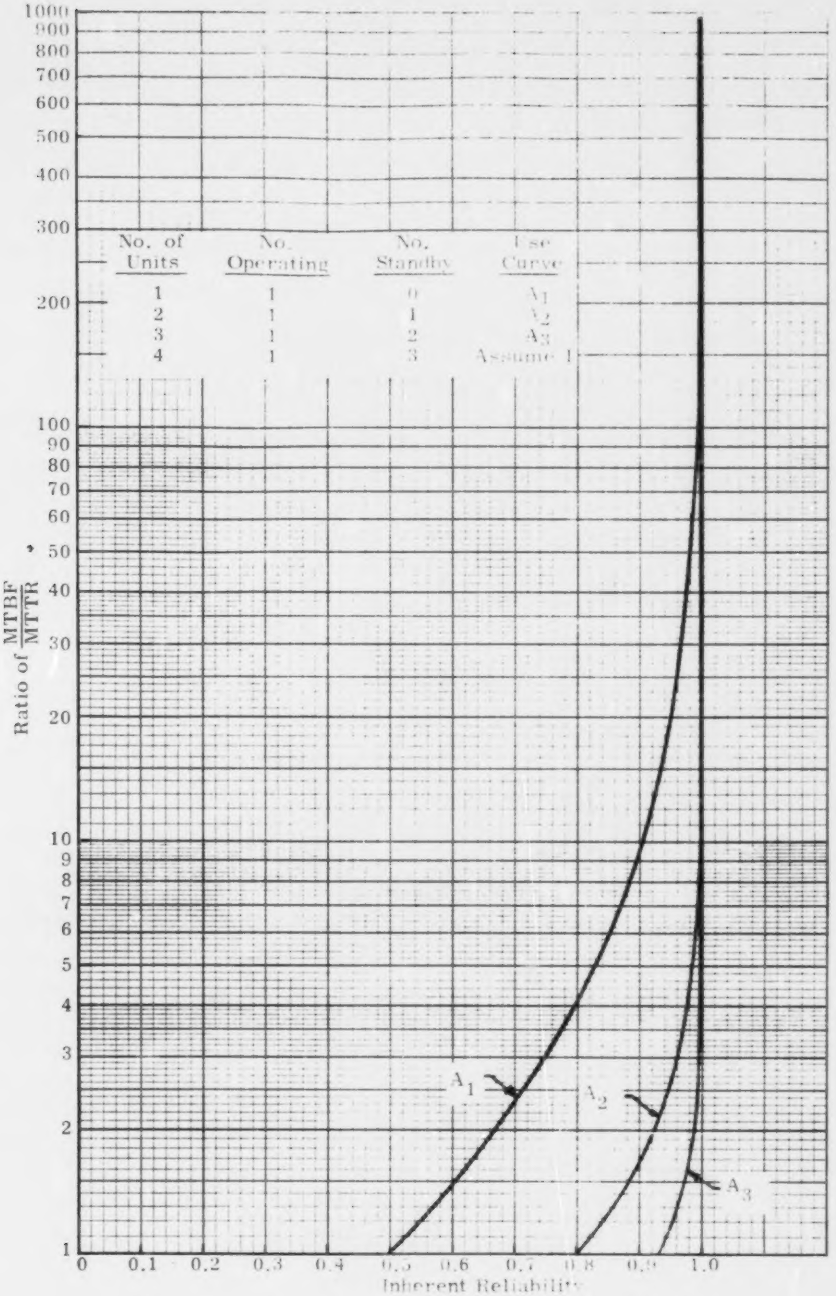
$$\text{MTTM} = \frac{T_r + T_p}{r + p}$$

where:

T_r = total elapsed repair time for r repairs

T_p = total elapsed time for p events

In computing achieved reliability, the same equations are used as for inherent reliability except MTBM and MTTM are substituted for MTBF and MTTR. The reliability can be read from Figure A-1 using the ratio of MTBM to MTTM in place of MTBF to MTTR.



No. of Units	No. Operating	No. Standby	Use Curve
1	1	0	A_1
2	1	1	A_2
3	1	2	A_3
4	1	3	Assume 1

Figure A-1. Steady State Reliability Allowing Multiple Repair for Simplex, Duplex, and Triplex Standby Redundancy

DATA COLLECTION AND ANALYSIS

Three water supply systems were visited to collect data for components. Some maintenance records and failure data were found, but most of the data resulted from discussions with system operators and maintainors. One system of the three had records which could be considered fair and which required engineering judgement to segregate failures from maintenance events. The data were tabulated and reliability values were calculated. Component reliabilities are shown in Figure A-2. The data in Figure A-2 are sufficient to demonstrate the rating concept; however, the use of the data for formal reliability analysis is not recommended since most of the data are estimates based on water system operator and maintainor experience. The estimates have not been verified. Future efforts should include data collection and verification in order to build an accurate reliability data bank.

MODELING AND RELIABILITY ANALYSIS

Each subsystem of the water supply system is structured by tracing the operations on the subsystem structure given in each appendix, C, D, E, F, and G. An operation is the lowest designated process on each structure and is identified by an eight-digit number having ciphers as the last two or three (usually three) digits. The structures are staging diagrams used to identify operations, functions, and subsystems. The order of designator numerals is:

X	System
XX	Subsystem
XXX	Function
XXXX	Subfunction
XXXXX	Operation
XXXXXX	Suboperation
XXXXXXOO	Last two ciphers left open for expansion as required.

NOTE: X is a whole number from 1 to 9 or letter from A to Z.

(Sheet 1 of 2)

COMPONENT	MTBF	MTTR	MTBM	MTTM	RATIO MTBF/MTTR	RATIO MTBM/MTTM	INHERENT RELIABILITY 1-RUN 0-STBY	INHERENT RELIABILITY 1-RUN 1-STBY	INHERENT RELIABILITY 1-RUN 2-STBY	INHERENT RELIABILITY 1-RUN 3-STBY
AERATOR	130,568	17.2	803	3.2	7,591	251	.9998	1-	1-	1-
AIR BLOWER/COMPRESSOR	22,769	27.0	173	15.5	843	11	.9988	1-	1-	1-
ALUM FEEDER	1,087	8.8	619	12.3	124	50	.9919	.9999	1-	1-
ALUM STORAGE TANK	12,045	17.2	12,045	3.2	700	3,764	.9985	.9999	1-	1-
ANNUNCIATOR SYSTEM	183,960	59.0	183,960	59.0	3,118	3,118	.9996	1-	1-	1-
BASINS & CLEARWELLS	53,755	91.4	7,300	83.6	588	87	.9983	.9999	1-	1-
CARBON SYSTEM	9,141	9.6	3,563	3.7	952	963	.9989	.9999	1-	1-
CHLORINATOR	16,994	44.3	65	12.3	384	5	.9973	.9999	1-	1-
CHLORINE EVAPORATOR	5,297	7.3	1,631	3.0	92	544	.9986	.9999	1-	1-
Cl_2 BOTTLE/TANK	192,720	70.0	192,720	70.0	2,753	2,753	.9996	1-	1-	1-
CONTROL AIR SYSTEM	22,769	27.0	173	15.5	843	11	.9988	.9999	1-	1-
CONTROL & MONITOR INSTR. SYSTEM	47,304	52.2	2,098	15.7	906	134	.9988	1-	1-	1-
DAM, DIKE, STRUCTURE	70,080	44.0	61,320	50.5	1,593	1,214	.9993	.9999	1-	1-
DIAL INDICATOR	142,182	4.9	142,182	3.6	29,017	39,495	.9999	1-	1-	1-
DISTRIBUTION PIPE (MAINS)	*	132.0	*	135.0						
DRAINS, SUMP, & OVERFLOW	52,560	12.5	52,560	12.5	4,205	4,205	.9997	1-	1-	1-
ELECTRIC POWER & SWITCHGEAR	19,542	17.2	7,817	8.9	1,136	878	.9991	.9999	1-	1-
FAN, VENTILATION	18,827	17.2	18,827	3.2	1,095	5,883	.9990	.9999	1-	1-
FILTER CONTROLS, RATE & BACKWASH	55,741	17.2	14,202	11.3	3,241	1,257	.9996	.9999	1-	1-
FILTER SWEEP	22,876	36.0	22,475	38.6	635	582	.9984	.9999	1-	1-
FIXED SCREEN	173,886	20.5	2,643	18.3	8,482	144	.9998	1-	1-	1-
FLOCCULATOR, PADDLE WHEEL	10,011	157.2	571	61.2	64	9	.9845	.9998	.9999	1-
FLUORIDE FEEDER	9,556	57.5	80	3.2	166	25	.9940	.9999	1-	1-
FLUORIDE TANK	12,045	17.2	12,045	3.2	700	3,764	.9985	.9999	1-	1-
GRAVITY SAND FILTER	55,654	92.6	43	23.4	601	2	.9983	.9999	1-	1-
HEATING SYSTEM	5,256	51.2	73	4.1	103	18	.9903	.9999	.9999	1-
LEVEL CONTROLS	78,341	17.2	78,341	3.2	4,555	24,482	.9997	1-	1-	1-
LIME SLAKER & FEEDER	3,956	14.4	49	10.0	275	5	.9963	.9999	1-	1-
LIME STORAGE TANK	12,045	17.2	12,045	3.2	700	3,764	.9985	.9999	1-	1-
METER, WATER	161,118	17.2	161,118	3.2	9,367	50,349	.9998	1-	1-	1-
OZONATOR	16,994	44.3	65	12.3	384	5	.9973	.9999	1-	1-
PACKAGE CHILLER	52,560	37.0	96	20.0	1,421	5	.9992	.9999	1-	1-

Figure A-2. Component Reliability

(sheet 2 of 2)

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COMPONENT	MTBF	MTTR	MTBM	MTTM	RATIOS		INHERENT RELIABILITY			
					$\frac{MTBF}{MTTM}$	$\frac{MTBM}{MTTM}$	1-RUN 0-STBY R_I	1-RUN 1-STBY R_I	1-RUN 2-STBY R_I	1-RUN 3-STBY R_I
PRESSURE SAND FILTER	106,828	92.6	48	1.5	1,154	32	.9991	.9999	1-	1-
PROCESS PIPE & CONDUIT	68,985	74.6	47,990	9.1	925	5,274	.9989	.9999	1-	1-
PUMP, WATER	33,381	41.1	416	1.5	812	277	.9987	1-	1-	1-
RECORDER	4,181	4.9	3,939	3.6	853	1,094	.9988	.9999	1-	1-
RESERVOIRS	360,842	91.4	3,939	643.0	395	6	.9997	1-	1-	1-
SLUDGE SCRAPER MACHINE	17,520	24.0	14,016	24.0	730	584	.9986	.9999	1-	1-
SULFUR DIOXIDE SYSTEM	157,630	10.0	157,680	10.0	15,768	15,768	.9999	1-	1-	1-
TANK, WATER	560,265	17.2	86,140	3.2	32,574	26,919	.9999	1-	1-	1-
TRAVELING SCREEN	25,484	82.0	1,456	28.1	311	52	.9967	.9999	1-	1-
VALVE, CHECK	74,327	9.0	74,327	9.0	826	826	.9998	1-	1-	1-
VALVE, CONTROL	32,586	10.1	25,760	94.2	3,226	273	.9996	1-	1-	1-
VALVE, LINE STOP, MANUAL	269,971	4.0	248,295	7.7	67,493	32,246	.9999	1-	1-	1-
WELL CAP	243,331	20.5	243,331	20.5	11,870	11,870	.9999	1-	1-	1-
WELL CASING	243,331	20.5	243,331	20.5	11,870	11,870	.9999	1-	1-	1-

*Distribution mains reliability depend upon installed length and whether or not the mains are looped or are single lines such as with dead ends. See Appendix C and Figure C-2 for reliability.

Figure A-2 (Continued)

The structuring in this manner provides a numerical identification of each part of the urban water supply system.

After tracing out the operations on the subsystem structures, the components that constitute an operation are determined by plant survey and entered into Table A-1. A single Table A-1 should be filled in for each operation in the system. The number of installed components, required components for satisfactory operation, and standby components are determined for each entry in Table A-1. The reliability from Figure A-2 is entered in the appropriate column. If standbys are not installed, the reliability is entered into the first reliability column (fifth column from left). The reliability is raised to the power of the number of installed (and required) components in the third or fourth columns and the result is entered into the sixth column; the last column is left blank. If the component has standbys available, the appropriate reliability, depending on number of standbys, is found in Figure A-2 and entered into the seventh column; in this case, no entry is made in the sixth column. Special entries such as cross-connection potential should be noted and entered into the table. The reliability of the operation is the product of the reliabilities in the sixth and seventh columns. The calculations are shown at the base of Table A-1.

The operations comprising the subsystem are entered into Table A-2. The quantity of installed identical unit operations are entered into column (2) with required and standby operations in columns (3) and (4). The unit operation reliability calculated in Table A-1 is entered into column (5). If no standbys are installed, raise the R_i in column (5) to the N power and enter result into column (6), leaving column (7) blank. If standby operations are installed, find the reliability from Figure A-1 or A-2 as directed in column (7) and enter the reliability into column (7) leaving column (6) blank. Make the appropriate calculations shown at the base of Table A-2 and calculate the subsystem reliability.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: ____________________

Stage Identification Number: ____________

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R_i (from Fig. F-2)
				R (from Fig. F-2)	R_i^N	

Series Components Reliability = Product of R_i^N = R_1 =

Standby Components Reliability = Product of R_i = R_2 =

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = ___ x ___ = ___

Enter R in Column (5) of Table F-2.

TABLE A-2. SUBSYSTEM RELIABILITY

Subsystem Description:____

Stage Identification Number:____________________

(1) Operation Identification Number	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Unit Operation Reliability R_i	(6) If n=N, Compute R_i^N	(7) If n + s = N, enter R_i on curve R_1 in Fig. F-1, move horizontally to right, and read from R_2 or R_3 as appropriate for number of standbys

Series Operations Reliability = Product of $R_i^N = R_1 =$

Standby Operations Reliability = Product of $R_i = R_2 =$

Subsystem Reliability = Product of $R_1 \times R_2 =$ ___ x ___ = ___ = R_{ss}

Subsystem Historical Water Supply Capability = ____ = B_{ss}

Subsystem Ability to Furnish Water = $R_{ss} \times B_{ss}$ ____ x ____ = ____

The subsystem historical water supply capability is a factor calculated for subsystems 11, 12, and 13 only and the method for determining the value is given in Appendices C, D, and E.

The reliabilities are taken from Table A-2 for each subsystem and are entered into Figure H-1 of Appendix H (page H-2). The system reliability is the product of the subsystem reliabilities:

$$R_s = R_{11} \times R_{12} \times R_{13} \times R_{14} \times R_{15}$$

where:

R_s = reliability of the water system

R_{11} = reliability of subsystem 11, obtain raw water

R_{12} = reliability of subsystem 12, treat raw water

R_{13} = reliability of subsystem 13, distribute treated water

R_{14} = reliability of subsystem 14, provide water quality surveillance

R_{15} = reliability of subsystem 15, provide services

SPECIAL CONSIDERATIONS

When preparing the reliability model, specific care should be exercised to only include items that affect system operation or water quality. The failure modes and effects analysis in Appendix I provides guidelines for determining component effect on the reliability of the system.

It is noted that component age is not considered in the reliability modeling. There are two reasons that age is not considered:

1. In long-life systems such as water systems where repair or replacement of components is made on an as-needed basis, it can be shown that the system MTBF will become constant in time.[4, 5, 6] If the MTBF is

constant, no change in reliability will occur with respect to time in service.

2. In four water supply systems visited during the program, records of installation dates for components are not maintained following initial installation. As a result, the reliability data collected cannot be correlated with age.

Future data collection and verification should include a provision to verify the constant MTBF with respect to water system age.

When modeling the operations and subsystems, Figure A-3 and Table A-3 are included to offer assistance in modeling. The matrix in Figure A-3 shows typical component make-up of operations. Figure A-3 was prepared after visiting three water supply systems. If an operation is made up of components identical to the matrix of Figure A-3, the reliability for the operation can be obtained directly from Table A-3.

RELIABILITY RATING

The reliability of the system obtained from the above process must be normalized so that it will be a relative or comparative rating for all water systems. The reliability rating is a ratio of the reliability predicted using the procedures above and the highest reliability that could be attained by the same system given that all components and operations were as reliable as possible. This is accomplished by reviewing all entries into Table A-2 and making the same calculations as were previously performed; only this time, the highest achievable reliability for each entry is used. For operations where reliability data were calculated using Figures A-1, A-2, and A-3 and Table A-3, the highest attainable reliability for operations would be 0.9, 0.99, 0.999, or 0.9999, depending upon the accuracy to which the analysis was performed. The reliability figure is raised to the power of the number of such operations modeled and evaluated:

$$R_{HE} = (0.9999)^N$$

(sheet 1 of 2)

11111	11112	11121	11122	11211	11212	11221	11222	11311	11312	11321	11322	12111	12112	12113	12121	12122	12123	12124	12125	12126	12131	12141	12142	12143	12144	12145	122111	122112	12212	12221	12222	12223	12231	12232	12241	12242	12243	12244	12245	12246	123111	123112	123113	12312	12321	12331	Component
1			1		1		1						1	2							1	1				1			1				1	1													Pump, Water
1	1		1		1		1						1	2							1	1							1				1	1													Valve, Check
2	1	8	2	2	2	2	2	2	2	2	2		2	4							8	2					4	2	2	2			2	2							4						Valve, Line Stop, Manual
		1		1	1	1	1	1	1	1	1		1	1							4	1					2	1	1	2			6	6							2						Valve, Control
								1	1																				1					1													Tank, Water
	1																				1	1	1	1	1	1	1	1	1	1	1	1	1								1	1	1	1	1	1	Basins & Clearwells
		1								1	1																																				Reservoirs
		1	1	1	1							1	1	1										1																							Dam, Dike, Structure
																							1																								Aerator
																									1		1														1						Air Blower/Compressor
																																												1			Ozonator
															1	1	1	1	1	1															1	1	1	1	1	1							Chlorinator
																											1	1		1																	Lime Slaker & Feeder
																																														1	Fluoride Feeder
																1	1																			1	1										Chlorine Evaporator
															1	1	1	1	2	1															1	1	1	1	2	1							Cl_2 Bottle/Tank
																														1																	Alum Feeder
																																														1	Fluoride Tank
																											1	1		1																	Lime Storage Tank
																																										1					Sulfur Dioxide System
																																											1		1		Carbon System
																														1																	Alum Storage Tank
								1	1	1	1																															1	1	1	1	1	Recorder
								1	1	1	1																																				Level Controls
																																															Dial Indicator
1	1			1	1	1	1																				1	1	1			1															Meter, Water
																																															Control & Monitor Instr. System
																																															Annunciator System
																																															Control Air System
																																		1													Pressure Sand Filter
																																	1														Gravity Sand Filter
																																	1	1													Filter Controls, Rate & Backwash
																																	4														Filter Sweep
1	1	1	1	1	1	1	1	1	1	1	1		1	1							1	1	1	1	1	1	1	1		1		1	1	1							1	1	1	1	1	1	Process Pipe & Conduit
																																															Distribution Pipe (Mains)
														1																																	Drains, Sump & Overflow
1		1	1									1	1																																		Fixed Screen
			1											1																																	Traveling Screen
																																															Fan, Ventilation
																																															Electric Power & Switchgear
																															1																Flocculator, Paddle Wheel
																																															Heating System
																																															Package Chiller
																																1															Sludge Scraper Machine
1																																															Well Casing
1																																															Well Cap

Figure A-3. Matrix of Components in Typical Operations Based on Data After Visit to Three Water Systems

(sheet 2 of 2)

13111	13112	13121	13122	13211	13212	13221	13222	14111	14112	14211	14212	14221	14222	14311	14312	14411	14412	14421	14422	14423	14424	15111	15112	15121	15122	15211	15212	15213	15221	15222	15231	15232	15233	15234	15235	15236	Component
	1		1					See Parts I.C, II.C, & III.D																		See Part V									See Part V		Pump, Water
	1		1																																		Valve, Check
4	4	Q	Q	2	2	2	2																														Valve, Line Stop, Manual
2	2	2	1	1	1	1	1																														Valve, Control
				1	1																																Tank, Water
																																					Basins & Clearwells
						1	1																														Reservoirs
	1		1																																		Dam, Dike, Structure
																																					Aerator
																																					Air Blower/Compressor
																																					Ozonator
						1	1																														Chlorinator
						1	1																														Lime Slaker & Feeder
																																					Fluoride Feeder
																																					Chlorine Evaporator
						1	1																														Cl_2 Bottle/Tank
																																					Alum Feeder
																																					Fluoride Tank
						1	1																														Lime Storage Tank
																																					Sulfur Dioxide System
																																					Carbon System
																																					Alum Storage Tank
2	2	2	2	2	2	2	2																														Recorder
				1	1	1	1																														Level Controls
1	1	1	1	1	1	1	1																														Dial Indicator
	1	Q	Q																																		Meter, Water
																																1					Control & Monitor Instr. System
																																	1				Annunciator System
																															1						Control Air System
																																					Pressure Sand Filter
																																					Gravity Sand Filter
																																					Filter Controls, Rate & Backwash
																																					Filter Sweep
1	1																																				Process Pipe & Conduit
		Q	Q																																		Distribution Pipe (Mains)
																																					Drains, Sump & Overflow
																																					Fixed Screen
																																					Traveling Screen
																									1												Fan, Ventilation
																						1	1														Electric Power & Switchgear
																																					Flocculator, Paddle Wheel
																									1												Heating System
																									1												Package Chiller
																																					Sludge Scraper Machine
																																					Well Casing
																																					Well Cap

Figure A-3 (Continued)

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TABLE A-3. RELIABILITY OF TYPICAL OPERATIONS MADE UP OF COMPONENTS SHOWN IN THE MATRIX OF FIGURE F-3

OPERATION OR SUBOPERATION ID NO.	SINGLE UNIT VALUES				OPERATION INHERENT RELIABILITY		
	MTBF (HRS)	MTTR (HRS)	MTBM (HRS)	MTTM (HRS)	1-RUN 0-STBY	1-RUN 1-STBY	1-RUN 2-STBY
11111000	11,697	33.4	352	3.9	.9971	.9999	1-
11112000	16,073	50.5	1,766	33.4	.9968	.9999	1-
11121000	8,815	29.8	1,604	37.7	.9966	.9999	1-
11122000	8,027	50.9	283	8.8	.9936	.9999	1-
11211000	13,686	29.5	11,083	52.7	.9978	.9999	1-
11212000	7,648	31.6	396	3.7	.9958	.9999	1-
11221000	17,007	26.0	13,528	53.1	.9984	.9999	1-
11222000	9,784	28.2	401	3.1	.9971	.9999	1-
11311000	3,264	9.3	2,891	14.2	.9971	.9999	1-
11312000	3,264	9.3	2,891	14.2	.9971	.9999	1-
11321000	3,254	9.2	1,700	2.9	.9971	.9999	1-
11322000	3,254	9.2	1,700	2.9	.9971	.9999	1-
12111000	49,949	37.2	2,534	19.6	.9992	.9999	1-
12112000	6,688	44.3	314	8.0	.9934	.9999	1-
12113000	4,559	37.6	178	5.6	.9918	.9999	1-
12121000	3,955	17.2	62	12.0	.9956	.9999	1-
12122000	3,955	17.2	62	12.0	.9956	.9999	1-
12123000	3,955	17.2	62	12.0	.9956	.9999	1-
12124000	15,617	46.4	65	12.3	.9970	.9999	1-
12125000	14,446	48.2	65	44.3	.9966	.9999	1-
12126000	15,617	46.4	65	12.3	.9970	.9999	1-
12131000	3,423	23.9	352	11.2	.9936	.9999	1-
12141000	8,726	27.5	381	7.3	.9968	.9999	1-
12142000	30,213	33.5	6,336	72.6	.9988	.9999	1-
12143000	21,111	72.0	5,743	71.6	.9966	.9999	1-
12144000	12,984	51.5	168	17.0	.9960	.9999	1-
12145000	15,859	63.6	390	5.9	.9960	.9999	1-
12211000	1,939	32.7	20	13.1	.9663	.9994	1-
12212000	9,251	32.7	382	7.2	.9964	.9999	1-
12221000*	593	22.1	41	15.4	.9640	.9993	1-
12231100	11,215	53.7	43	23.9	.9952	.9999	1-
12231200	2,089	26.3	38	22.4	.9875	.9999	1-
12231300	2,089	26.3	38	22.4	.9875	.9999	1-
12232000	3,590	19.2	42	2.5	.9946	.9999	1-
12241000	3,955	17.2	62	12.0	.9956	.9999	1-
12242000	3,955	17.2	62	12.0	.9956	.9999	1-
12243000	3,955	17.2	62	12.0	.9956	.9999	1-
12244000	15,617	46.4	65	12.3	.9970	.9999	1-
12245000	14,446	48.2	65	44.3	.9966	.9999	1-
12246000	15,617	46.4	65	12.3	.9970	.9999	1-
12311100	8,551	30.7	666	15.4	.9964	.9999	1-
12311200	3,820	9.0	3,417	4.1	.9976	.9999	1-
12311300	2,741	9.1	1,764	3.8	.9966	.9999	1-
12312000	3,182	15.5	64	12.1	.9951	.9999	1-
12321000	2,741	9.1	1,764	3.8	.9966	.9999	1-
12331000	2,257	22.0	78	3.2	.9903	.9999	1-
13111000	1,757	7.2	1,607	15.2	.9959	.9999	1-
13112000	1,578	9.7	326	4.6	.9938	.9999	1-
13121000 13122000	DEPENDENT UPON PIPE LENGTH, VALVES, & METERS						
13211000	1,883	5.5	1,727	9.7	.9970	.9999	1-
13212000	1,883	5.5	1,727	9.7	.9970	.9999	1-
13221000	1,073	12.0	27	15.3	.9889	.9999	1-
13222000	1,073	12.0	27	15.3	.9889	.9999	1-
14111-14412	BACTERIOLOGICAL, PHYSICAL, & RADIOACTIVITY TESTING NOT INCLUDED IN THIS FIGURE.						
14421000	SEE FOOTNOTE						
14422000 14423000	NOT INCLUDED IN THIS FIGURE						
15111000	19,542	17.2	7,812	8.9	.9991	.9999	1-
15112000	19,542	17.2	7,812	8.9	.9991	.9999	1-
15121-15222	NO CALCULATIONS REQUIRED						
15231000	22,769	27.0	173	15.5	.9988	.9999	1-
15232000	47,304	52.2	2,098	15.7	.9988	.9999	1-
15233000	183,960	59.0	183,960	59.0	.9996	1-	1-

NOTE:

ID NO. 14421000: PROCESS CONTROLS INCLUDE Cl_2 RESIDUAL, HARDNESS, TESTS, pH MEASUREMENT, & TEMPERATURE MONITORING. DESIGN ADEQUACY = NO. CHECKED/4

*SUBFUNCTION (COMBINES 12221000, 12222000, & 12223000 OPERATIONS) where:

R_{HE} = highest attainable equipment reliability for system containing the N operations

N = number of operations

Use 0.9, 0.99, 0.999, or 0.9999, depending upon accuracy used in prediction (mathematically, the predictions should be carried to three places with results expressed to two places)

The normalized reliability rating is then the actual predicted equipment reliability divided by highest attainable reliability and the result is expressed to two places:

$$\text{Water system equipment reliability rating} = \frac{\text{water system predicted reliability}}{\text{highest attainable reliability}} = \frac{R_{11} \times R_{12} \times R_{13} \times R_{14} \times R_{15}}{R_{HE}}$$

Those operations relying on subjective evaluations must be separately evaluated:

R_{HS} = (product of R_{HS} for each subjective evaluation) = 1.0

The R_{HS} is used in the failure effects analysis in the following subsection.

FAILURE EFFECT RATING

The failure modes and probability of their occurrence can be used to determine the probable effect of a particular operations failure on the overall ability of the system to furnish quality water. Failure data were collected from three water supply systems; however, the data did not correlate component failures with effects on water quality. As previously stated, future efforts should include substantiation of failure modes and their probable effects on water quality. To demonstrate this concept, a weighting factor was developed for application to each operation. The weighting factor is used to assign higher weight to critical operations and less weight to less critical operations. For the demonstration of the concept for the rating system, weight factors below are assumed for determining component weighting factors and of criticality of component failure modes on system ability. They were developed from the failure modes and effects analysis in Appendix I.

Failure Effect	Weighting Factor for Detrimental Effect on System
1. Bacteria contamination	10
2. Physical constituent contamination	9
3. Contamination by one of the constituents on the recommended list	9
4. Contamination by one of the constituents on the mandatory list	10
5. Loss of water capacity and pressure	8
6. Loss of control of process	7
7. Loss of repair capability	5
8. Personnel hazard	10
9. Overload subsequent processes	8
10. Deterioration of system	5
11. Improper operation	7
12. Loss of efficiency (but not capacity)	4

As a result of performing a failure modes and effects analysis for operational processes, quality control surveillance, and human factors, the listing in Table A-4 gives criticality weighting factors for the operations given in the matrices in Appendices C, D, E, F, and G. Table A-4 was prepared by obtaining the product of the 12 weighting factors. (See Figure A-4 which gives an example of this technique.) Weighting factors are entered into Table A-5 for each operation listed in the completed Table A-2. All subjective evaluations and ratings are also entered. Fill in a Table A-5 for each subsystem.

(Sheet 1 of 3)

TABLE A-4. CRITICALITY WEIGHTING FACTORS FOR OPERATIONS

Number	Name	Failure Effects Weighting Factor
11111000	Obtain from wells	5040
11112000	Obtain from springs or infiltration galleries	5040
11121000	Obtain using impoundments	145152000
11122000	Obtain directly from streams	14515200
11211000	Gravity feed to storage	5040
11212000	Pump to storage	352800
11221000	Gravity feed to treatment	5040
11222000	Pump to treatment	352800
11311000	Store in elevated tank	3528
11312000	Store in ground level tank	3528
11321000	Store in lined reservoir	3528
11322000	Store in earthen reservoir	3528
12111000	Coarse screen raw water	16128
12112000	Fine screen raw water	16128
12113000	Micro strain raw water	145152
12121000	Direct feed chlorine gas	1411200
12122000	Chlorinate	1411200
12123000	Evaporate and chlorinate	1411200
12124000	Dry hypochlorite feed	1411200
12125000	Hypochlorite solution feed	1411200
12126000	Chlorine dioxide feed	1411200
12131000	Plain settle raw water	288
12140000	Aerate raw water	907200
12211000	Soften with lime-soda-ash	508032000
12212000	Soften with ion exchange	62720
12220000	Coagulate, flocculate, sediment	508032000
12231000	Gravity filter	6350400
12232000	Pressure filter	6350400
12241 through 12246	Same as 12121000	1411200

(Sheet 2 of 3)

TABLE A-4; (Continued)

Number	Name	Failure Effects Weighting Factor
12311000	Dechlorinate water	441
12312000	Ozonate water	176400
12321000	Treat with carbon	158760
12331000	Add fluoride	176400
13111000	Gravity feed to storage	63504000
13112000	Pump to storage	63504000
13121000	Gravity feed to demand	7056000
13122000	Pump to demand	7056000
13211000	Store in elevated tanks	7056000
13212000	Store in ground level tanks	7056000
13221000	Store in lined reservoir	63504000
13222000	Store in earthen reservoir	63504000
14111000 14112000	Sample and test for bacteria test	2450
14200000	Test for chemical constituent concentration	22050
14300000	Test for physical characteristics	2205
14410000	Test for radioactivity	10
14420000	Test for control of process operations	63504000
15110000	Provide power	6272000
15121000	Provide sanitary items	2800
15122000	Habitability items (Human engineering)	280
15211000 15212000 15213000	Preventive maintenance program (Part V.C.4)	508032000
15221000 15222000	Corrective maintenance program (Part V.D)	2540160000
15231000	Control equipment	6272000
15232000	Monitoring equipment	78400
15233000	Alarm system	627200

(sheet 3 of 3)

TABLE A-4, (Continued)

		Failure Effects Weighting Factors
15234000	Operating schedule	62720
15235000	Operating labor	508032000
15236000	Operating instructions	508032000
Appendix A, para. C. 3. d	Protection from environmental influences	256
para. C. 3. e	Reliability of source control	14515200
Appendix B, para. B. 2	Special reliability problems in treatment	14515200
Appendix C para. A. 3. f	Pressure reliability at peak demand	2800
para. C. 2	Dead ends	450
para. C. 3	Flow interruptions	320
para. C. 4	Small mains (3 inches)	320
para. C. 5	Disinfection following repair	10
para. C. 6	Leak repair adequacy	320
para. C. 7	Cross-connection program	40500
para. C. 8	Valve maintenance	160
Appendix D, para. B	Laboratory reliability	63504000
Appendix E, para. B. 2	Safety equipment	78400

Operation		Failure Effects Weighting Factors													Operation Failure Effects Weighting Factor
Number	Name	1	2	3	4	5	6	7	8	9	10	11	12		
	Weighting Multipliers	10	9	9	10	8	7	5	10	8	5	7	4		Product
11111000	Obtain from wells	10	9			8	7								5040
11112000	Obtain from springs or Infiltration galleries	10	9			8	7								5040
11121000	Obtain using impoundments	10	9	9	10	8	7		10	8			4		145152000
11122000	Obtain directly from streams	10	9	9	10	8	7			8			4		14515200
11211000	Gravity feed to storage			9	10	8	7								5040

Figure A-4. Example of Determining Criticality Weighting Factors for Operations

TABLE A-5. OPERATION RELATIVE FAILURE EFFECT

(1) Operation Number (From Table F-2)	(2) Failure Effect Weighting Factor, F (From Table F-4)	(3) Operation Weight Factor Fraction $1-(F_i \div \sum_{i=1}^{n} F_i)$	(4) Actual Operation Reliability, R_i (From Table F-2)	(5) Highest Operation Achievable Reliability, R_h	(6) Actual Operation Failure Effect (3) x (4)	(7) Lowest Operation Failure Effect (3) x (5)	(8) Operation Rating (6) ÷ (7)
Summation, $\sum_{i=1}^{n} F_i$ = ________		System Failure Effect Rating $\frac{\sum_{i=1}^{n} [(6) \div (7)]_i}{n}$ = ________					

The factors are summed for all operations and the weight factor fraction of each operation is determined by dividing its weighting factor by the total number of entries and subtracting from one. The operation failure effect is obtained by multiplying the fraction by the actual reliability and the highest achievable reliability. The ratio of the actual failure effect to the lowest failure effect is the rating for the operation. The subsystem failure effect rating is the average of the failure effect ratings of operations in each subsystem. The system failure effect rating is the average of all of the operation failure effect ratings. The failure effect rating is used in the composite rating in Appendix H.

APPENDIX B

WATER QUALITY ANALYSIS

The procedures below are used in rating the ability of the water supply system to meet the constituent limits of the Public Health Service Drinking Water Standards of 1972 and to rate the adequacy of the system to furnish water meeting those requirements.

PROBABILITY OF MEETING THE PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS

1. Number of bacteriological examinations performed:

Yearly ________ Twice a year ________ Monthly 52

Weekly ________ Daily ________ Other (Explain) ________

____

2. From system records for bacteriological, chemical, physical, and radiological records, make the following analyses:

   a. For each constituent in the U.S. Public Health Service DWS (Drinking Water Standards), compute the mean concentration and estimate the standard deviation from the data. The calculations are illustrated in Figures B-1 and B-2.

   b. The results of the calculations are tabulated in Figure B-3. If only one test result is available for a constituent, the deviations in Figure B-4 may be used but only one sample should be entered under the column, N, No. of test results in Figure B-3. After entering the data into Figure B-3, make the calculations shown through calculating the z-scores for the standard normal distribution.

   c. The z-scores in Figure B-3 are entered on the graph of Figure B-5, and the probability is read at the

List the test results for a constituent in order from low to high concentrations. Indicate the frequency of occurrence for each result. List cumulative frequency, calculate cumulative percent, and multiply frequency by test results.

	x_i Test Results	f_i Frequency	F_i Cumulative Frequency	% $\frac{F_i}{\Sigma f_i} \times 100$	$x_i f_i$
Constituent (1)	1 mg/ℓ	1	1	7.7	1
	2 mg/ℓ	3	4	30.8	6
	3 mg/ℓ	1	5	38.5	3
	4 mg/ℓ	4	9	69.2	16
	5 mg/ℓ	2	11	84.6	10
	6 mg/ℓ	1	12	92.3	6
	7 mg/ℓ	1	13	100.0	7
		$\Sigma f_i = 13$			$\Sigma x_i f_i = 49$

$$\bar{x} = \text{mean or average concentration} = \frac{\Sigma x_i f_i}{\Sigma f_i} = \frac{49}{13} = 3.8 \text{ mg}/\ell$$

The standard deviation, σ, is found by plotting the cumulative percent versus the test results on normal probability paper (see Figure B-2). A straight line is fitted by eye to the data; when fitting the line, the lowest and highest plotted data points are ignored. Roughly 68 percent of data (which are normally distributed) will fall between one standard deviation below the mean and one standard deviation above the mean. From this, an estimate of the standard deviation is obtained by reading off values corresponding to 16 percent and 84 percent and dividing the difference between these two values by two. For the example, the standard deviation is estimated as $5.5 - 1.3/2 = 2.1$. If a calculator is available, the standard deviation is calculated using the following formula.[9]

$$\sigma = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{\Sigma f_i}}$$

Figure B-1. Calculation of Sample Mean and Estimation of Standard Deviation for Constituents

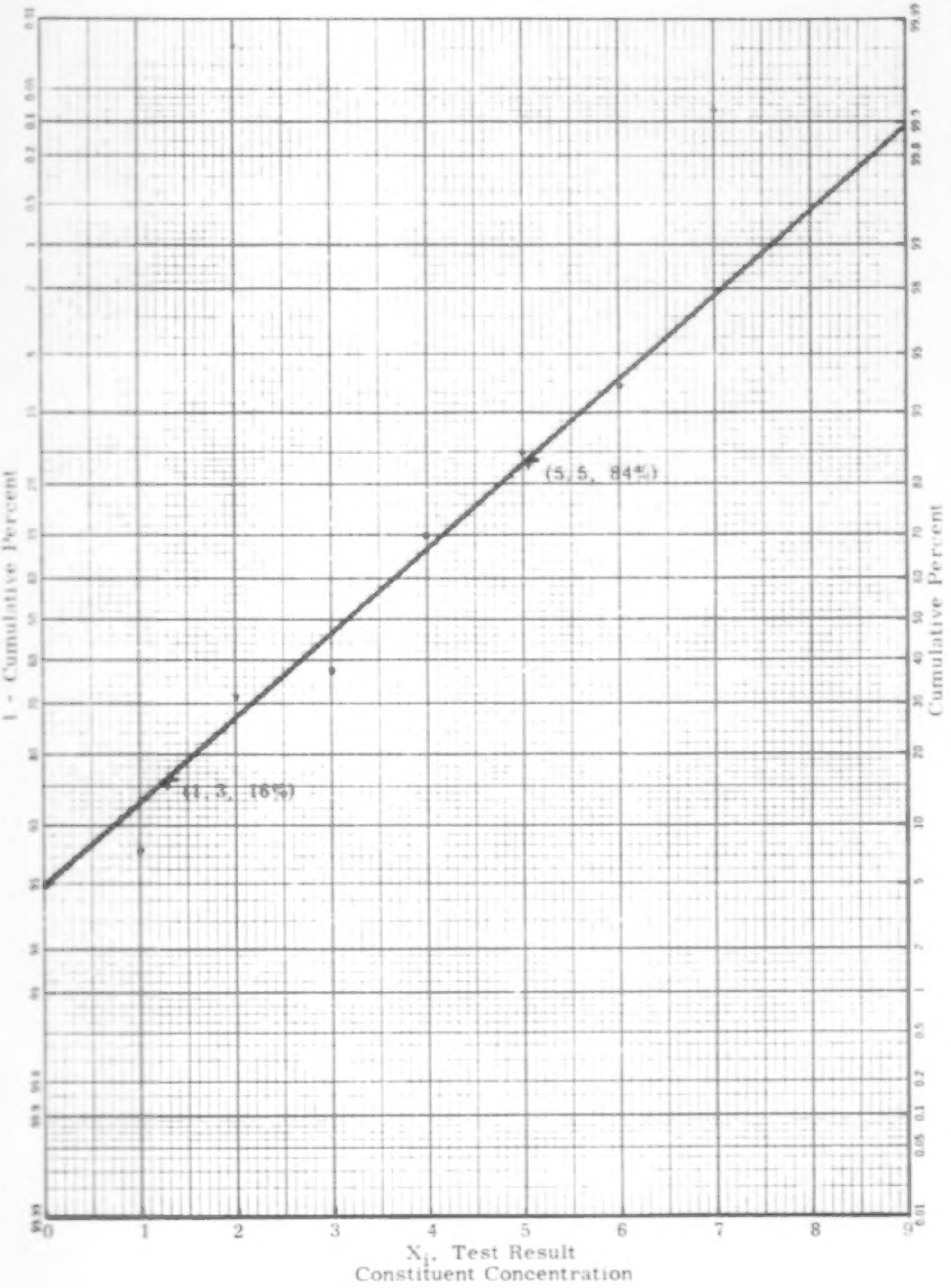

Figure B-2. Example of Estimating the Standard Deviation of Constituent Concentration Test Results

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(sheet 1 of 2)

WATER CONSTITUENT DATA

Use Certified Laboratory Sources Only

Data Sources: Treatment Laboratory ________ County Health Department ________ State Health Department ________

Water Supply System: Name ________
Location ________

Data for: Raw Water ________ Treated Water ________ Distributed Water ________

Constituent	Public Health Service Drinking Water Standards Recommended Limit, X_1	Public Health Service Drinking Water Standards Mandatory Limit, X_2	Laboratory Water Test Results $\bar{X}$ Mean	Laboratory Water Test Results s Deviation	Laboratory Water Test Results N, No. of Tests	95% Confidence Limits $\bar{X}' = \bar{X} + \frac{2s}{\sqrt{n}}$	95% Confidence Limits $\bar{X}'' = \bar{X} - \frac{2s}{\sqrt{n}}$	Z-Score Values $\frac{X_1 - \bar{X}'}{s}$	Z-Score Values $\frac{X_2 - \bar{X}}{s}$	Z-Score Values $\frac{X_L - \bar{X}}{s}$	Z-Score Values $\frac{X_1 - \bar{X}'}{s}$	Probability of Exceeding DWS Recommended Limit	Probability of Exceeding DWS Mandatory Limit
Nonremovables:										For Fluoride Only	For Fluoride Only		
Alkyl Benzene Sulfonate, ABS	0.5 mg/l												
Arsenic, As	0.01	0.05 mg/l											
Barium, Ba		1.0											
Cadmium, Cd		0.01											
Chromium, Hexavalent, Cr^{+6}		0.05											
Chloride, Cl	250.												
Copper, Cu	1.0												
Carbon Chloroform Extract, CCE	0.2												
Cyanide, CN	0.01	0.2											
Lead, Pb		0.05											
Nitrate, NO_3	45.												
Selenium, Se		0.01											
Silver, Ag		0.05											
Sulfate, SO_4	250.												
Zinc, Zn	5.												
Radium-226		3μμc/l											
Strontium-90		10μμc/l											
Removables:													
Coliform	(a) X_1 or X_2 10% [illegible] /month using 10 ml portions												
	(b) [illegible] using 10 ml portions [illegible] of 3 consecutive samples [illegible] when [illegible] per month, or [illegible] when [illegible] samples/month												
	(c) 1/100 ml avg. [illegible] or [illegible] 100 ml, [illegible] 100 ml, [illegible] 100 ml												
Color	15 units												

Figure B-3. Calculations for Probability of Exceeding the Drinking Water Standards

(sheet 2 of 2)

Constituent	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Score Values				Probability of Exceeding DWS:[1]	
	Recommended Limit, X_1	Mandatory Limit, X_2	$\bar{X}$ Mean	σ Deviation	N, No. of Tests	$\bar{X}' = \bar{X} + \frac{2\sigma}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\sigma}{\sqrt{n}}$	$\frac{X_1 - \bar{X}'}{\sigma}$	$\frac{X_2 - \bar{X}'}{\sigma}$	$\frac{X_L - \bar{X}''}{\sigma}$	$\frac{X_U - \bar{X}'}{\sigma}$	Recommended Limit	Mandatory Limit
Removables (Cont'd)													
Fluoride, F	Avg. Temp.	F(LWR) X_L F (Upper) X_U											
	50.0-53.7°F	0.9 1.7											
	53.8-58.3°F	0.8 1.5											
	58.4-63.8°F	0.8 1.3											
	63.9-70.6°F	0.7 1.2											
	70.7-79.2°F	0.7 1.0											
	79.3-90.5°F	0.6 0.8											
Iron, Fe	0.3 mg/ℓ												
Manganese, Mn	0.5 mg/ℓ												
Odor, Threshold Number	3												
Phenols	0.001 mg/ℓ												
Tastes	Not objectionable												
Total Dissolved Solids, TDS	500. mg/ℓ												
Turbidity	5 units												

[1] In 2 consecutive samples, or in >1 sample when <20 samples/month, or in >5% of samples when >20 samples/month.

Control Characteristics Measurement (Treated and Distributed Water)

Aluminum	0.05 mg/ℓ												
Chlorine Residual	0.4 mg/ℓ												
Hardness	80 mg/ℓ												
Pb	X_L X_U 5.6 9.5												

Figure B-3.(Continued)

Nonremovable Constituents	Standard Deviation Stream Source (mg/ℓ)	 Controlled Watershed Source	 Groundwater Source (mg/ℓ)
ABS	.01	.01	0.*
As	.002*	.002	.002*
Ba	.012	.02	.02*
Cd	.003	.0004	.0004*
Cr^{+6}	.002	.002	.002*
Cl	3.0	6.0	3.0
Cu	.01	.03	.001*
CCE	.5	.5*	0.*
CN	.01*	.01*	0.*
Pb	.005	.009	.009*
NO$_3$	.5	2.0	.05
Se	.005*	.005	.005*
Ag	.001*	.001	.001*
SO$_4$	6.0	2.0	2.0
Zn	.02	.01	.01*
Ra^{226}	----------------	No Data	----------------
Sr^{90}	----------------	No Data	----------------

Removable Constituents, Treatment Facility	From Surface Water Source	Groundwater Source
Color	.3 units	.4 units
Fe	.03 mg/ℓ	.1 mg/ℓ
F (@ 60°F average air temperature)	.03 mg/ℓ	.2 mg/ℓ
Mn	.002 mg/ℓ	.001 mg/ℓ
Odor (threshold number)	.6	.6
Phenols	.001 mg/ℓ	≈0. mg/ℓ*
Tastes	–	–
TDS	20. mg/ℓ	9. mg/ℓ
Turbidity	.2 units	.05 units
Coliform MPN/100 ml	.05 MPN/100 ml	≈0. MPN/100 ml

Removable Constituents, Distribution		
Coliform	.12 MPN/100 ml	.03 MPN/100 ml
Color	.3 units	.4 units
Fe	.03 mg/ℓ	.18 mg/ℓ
F (@ 60°F average air temperature)	.03 mg/ℓ	.2 mg/ℓ
Mn	.002 mg/ℓ	.001 mg/ℓ
Odor (threshold number)	.6	.6
Phenols	.001 mg/ℓ	≈0. mg/ℓ*
Tastes	–	–
TDS	16. mg/ℓ	19. mg/ℓ
Turbidity	.2 units	.05 units

*Estimates, data not available

Note: These deviations were calculated from data from three systems in the Maryland area and caution is advised in areas where water sources are significantly different.

Figure B-4. Typical Standard Deviations for Water Constituent Concentrations

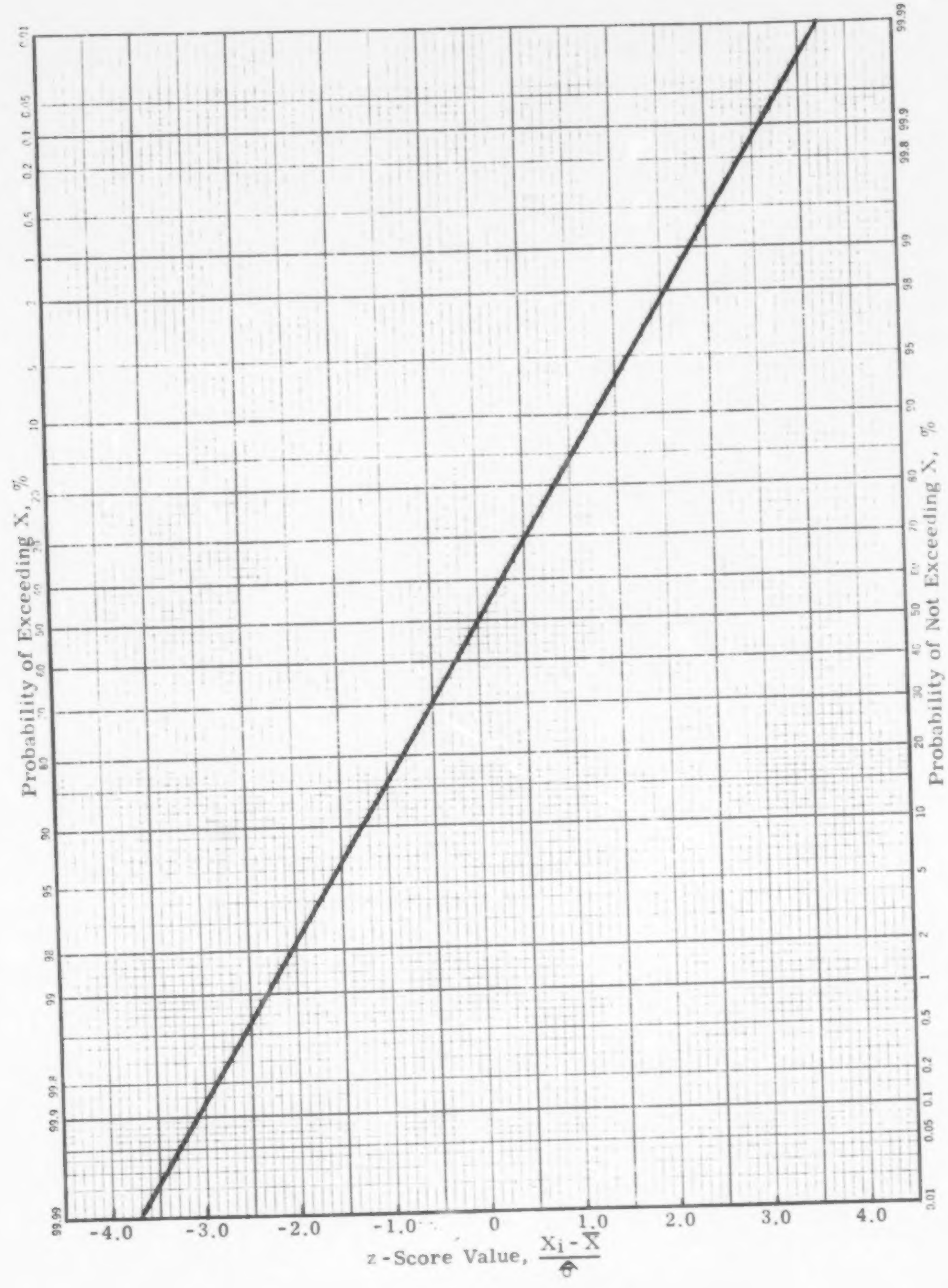

Figure B-5. Graph of z-Score Values and Standard Normal Probabilities intersection of the z-score and the straight line which is a plot of the areas (probabilities) for the standard normal distribution.[9] The probability of exceeding a constituent limit is read from the left ordinate. For fluoride and pH only, the upper z-score is read from the left ordinate of Figure B-5 and the lower z-score is read from the right ordinate; the probability of not exceeding the fluoride and pH range is obtained by subtracting the sum of the two probabilities from one. If data are not available for a constituent, assume 50 percent on Figure B-3; or, if that constituent is to be ignored, disregard and enter a dash in Figure B-3.

3. Cross-connection potential in a system is related to the probability of a cross-connection occurrence and the probability of exceeding the DWS. It is computed by multiplying the reliabilities of the components that affect the cross-connection, subtracting the product from one to obtain the probability of failure, multiplying by the probability of exceeding the DWS due to the cross-connection, and entering the result into Figure B-3. One minus the result is the probability of not having an effect and should be entered into subsystem and operation reliability calculations in Appendix A.

3. The probabilities of exceeding the limits are calculated for each constituent for each of subsystems 11, 12, and 13 which covers the raw water source, treated raw water, and distributed treated water. All three are calculated in order to obtain a design adequacy rating (discussed below).

WATER QUALITY RATING

In order to achieve a single composite rating, the probability for each constituent must be weighted. The weighting factors from Appendix A (page A-18) are used in the weighting. The probabilities for distributed water only (Figure B-3) are entered into Figure B-6, multiplied by the weighting factor, and averaged to obtain the rating for the ability of the system to meet the drinking water standards. If the system is rated using only a few of the constituent limits in Figure B-6, then only those constituents considered should be used in Figure B-6; likewise, only the weight factors for those constituents considered should be summed to obtain the average rating divisor. In this manner, as many constituents as desired can be included in the rating. The water quality rating is used in Appendix H to determine the system composite rating.

SYSTEM DESIGN ADEQUACY

The design adequacy is the measure of the ability to remove constituents from raw water or prevent contamination of finished water. It is measured as a comparison between the quality of the raw water and the quality of the finished water to give a relative measure of the ability of the system to cope with the raw water source and consistently meet the constituent limits of the drinking water standards.

To calculate the adequacy, a Figure B-6 is completed for the raw water source and the treated water in addition to the distributed water. The following calculations are made to determine design adequacy.

1. Design adequacy of treatment, D_{12}:

$$D_{12} = \frac{\overset{(1-.01)\ -\ (1-\text{UNK})}{(1\text{-Rating}_{11}) - (1\text{-Rating}_{12})}}{1\text{-Rating}_{11}} =$$

NOT CALCULATED DUE TO LACK OF TEST DATA AT CLEARWELL OF DEMONSTRATION SYSTEM.

where

Rating_{11} = rating of quality of raw water source

Rating_{12} = rating of quality of raw water treatment

Note: Maximum result = 1.00

2. Design adequacy of distribution, D_{13}:

$$D_{13} = \frac{(1\text{-Rating}_{13}) - (1\text{-Rating}_{12})}{1\text{-Rating}_{13}} =$$

NOT CALCULATED DUE TO LACK OF TEST DATA FOR CLEARWELL OF DEMONSTRATION SYSTEM.

where

Rating_{13} = rating of quality of distribution

Note: Maximum rating = 1.00

3. System design adequacy, D_s:

$$D_s = \frac{\overset{(1-.01)-(1-.85)}{(1\text{-Rating}_{11}) - (1\text{-Rating}_{13})}}{\underset{(1-.01)}{1\text{-Rating}_{11}}} =$$

.85 FOR DEMONSTRATION SYSTEM.

Note: Maximum rating = 1.00

The system design adequacy is used in Appendix H to determine the composite rating.

Column (4) in Figure B-6 is the rating for each constituent. Column (5) is a measure of the criticality of each constituent rating with respect to the overall rating for distributed water quality.

(1) Constituent	(2) Weight Factor	(3) $\frac{1-P(\geq DWS)}{P(\geq DWS) \text{ from Fig. G-3}}$	(4) (2) x (3)	(5) $(2) \times (3) \div \frac{\sum_{i=1}^{n} \lvert(2) \times (3)\rvert_i}{\sum_{i=1}^{n}(2)_i}$
Bacteria:				
Coliform	10			
Physical:				
Turbidity	9			
Color	9			
Threshold Odor	9			
Taste	9	See end of Appendix G for		
Chemical, Recommended:		demonstration system.		
ABS	9			
As	9			
Cl	9			
Cu	9			
CCE	9			
CN	9			
Fe	9			
Mn	9			
NO_3	9			
Phenols	9			
SO_4	9			
TDS	9			
Zn	9			
Chemical, Mandatory:				
As	10			
Ba	10			
Cd	10			
Cr^{+6}	10			
CN	10			
F	10			
Pb	10			
Se	10			
Ag	10			
Radioactivity:				
Ra^{226}	10			
Sr^{90}	10			
			$\sum_{i=1}^{n} \lvert(2) \times (3)\rvert_i =$	
			$\frac{\sum_{i=1}^{n} \lvert(2) \times (3)\rvert_i}{\sum_{i=1}^{n}(2)_i} =$ ______	

Figure B-6. Rating of System Ability to Meet Constituent Limits of Public Health Service Drinking Water Standards of 1962

APPENDIX C

SURVEY OF RAW WATER SOURCE

A. Source Quantity Data

1. Source of Supply

	Number	Minimum Safe Daily Drought Period Yield, MGD, at Intake
Springs	0	—
Wells	0	—
Impoundments	1	0.5
Streams	3	12.1
Borrowed ~~Purchased~~ Water	1	2.0

Total: 14.6 MGD

2. System Demand Over Past Five Years (MGD)

Year	Average	Peak Day	Peak Hour
1971	4.032	4.800	7.64
1970	3.800	5.075	—
1969	4.078	5.288	—
1968	4.004	5.700	—
1967	3.500	5.600	—

3. Estimate Demand Five Years From Present

Year	Average	Peak Day	Peak Hour	Fire Flow
1980	5.44	7.94	10.88	7.9

4. For Groundwater Sources

NOT APPLICABLE TO THE DEMONSTRATION SYSTEM

a. Is static groundwater falling? ____

b. Is the specific capacity of wells decreasing? ____

5. For Surface Water Sources

a. Size of impoundment and tributary watershed? 1070 Square Miles

b. Storage capacity of impoundments? 147 Million Gallons

c. Days storage at present demand? 36 Days

d. Days storage at maximum demand ~~five~~ years from present? 1980 27 Days

6. Has the system ever discontinued or curtailed service to consumers due to lack of source quantity? No

a. Times per year? 0

b. Days per time? – (Avg.)

c. Calculate historical water source supply capability

$$B_s = \frac{365 - (b \overset{0}{\times} a)}{365} = 1.0$$

B. Source Reliability

1. Of sources in A. 1 above, what existing combinations will meet maximum demand five years from now?

	N Number (From A. 1)	n Number Required	S Number Standby
a. Springs	0	0	0
b. Wells	0	0	0
c. Impoundment (30 day minimum)	1	1	0
d. Stream (storage for 30 day minimum) *	3	2	0
e. Purchased Water (noninterruptible)	0	0	0

* Supply during low flow

2. Reliability Modeling. Using Matrix of Figure C-1 and the methods of Appendix A, make the reliability model of the source subsystem. Circle the appropriate operations in Figure C-1 and compute the reliability using the method of Appendix A. Calculate the failure effects rating for each unit operation in accordance with Appendix A. See pages C-7 through C-23 for the demonstration system.

3. The reliability result is the probability that the raw water source will furnish water at all times to meet the demand five years from the present. This is the reliability of the subsystem, named Obtain Raw Water, to consistently furnish raw water. The reliability calculation is the product of the reliabilities of all required unit operations.

C. Other Considerations

1. Refer to the failure modes and effects analysis (Appendix I, Figure I-2) for operations in subsystem 11, Obtain Raw Water, to determine effects of failures on system reliability. These effects are considered when modeling the system for reliability analysis.

2. The probabilities of exceeding the constituent limits of the drinking water standards and the water rating for the subsystem should be calculated using Appendix B. See pages C-24 through C-36 for the demonstration system.

3. Several qualitative questions pertaining to source quality should be answered:

   a. Does the source exceed bacteriological, chemical, physical, or radiological requirements of the DWS?

YES

b. If the DWS are exceeded, is the water treated to reduce their concentration? YES

c. Are records kept on file for the examination? YES

Is the functioning of intake facilities immune to interruption by:

Floods? NO

Ice? Yes

Plugging from debris or sand? Yes

High winds? Yes

Ice storms? Yes

Power failures? No

Breaks? Yes

Overhaul? Yes

Damage from boats, automobiles, etc.? Yes

7 out of 9

e. Are sources controlled? No

i. Are groundwater sources located as far as practicable from a source of pollution, protected from access and pollution by an animal, properly designed with surface drains away from source, and surveyed with respect to sinkholes, abandoned wells/bores, fissures, and faults over the aquifer or source? ______ Does water quality change following a heavy rainfall? ______. If yes, this a sign of surface leakage into well.

NA

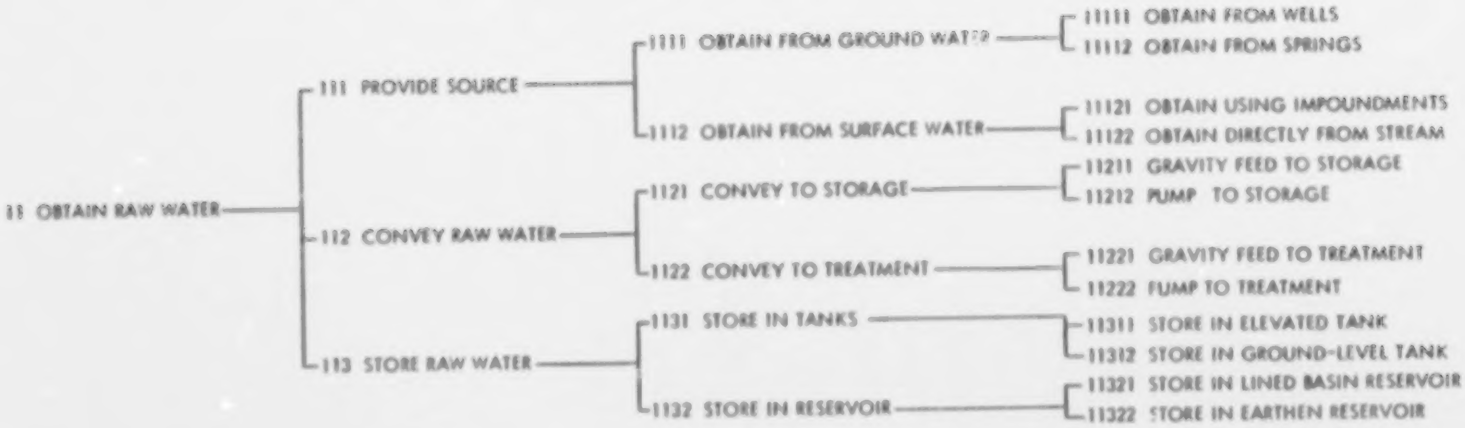
11 OBTAIN RAW WATER
111 PROVIDE SOURCE
112 CONVEY RAW WATER
113 STORE RAW WATER
1111 OBTAIN FROM GROUND WATER
1112 OBTAIN FROM SURFACE WATER
1121 CONVEY TO STORAGE
1122 CONVEY TO TREATMENT
1131 STORE IN TANKS
1132 STORE IN RESERVOIR
11111 OBTAIN FROM WELLS
11112 OBTAIN FROM SPRINGS
11121 OBTAIN USING IMPOUNDMENTS
11122 OBTAIN DIRECTLY FROM STREAM
11211 GRAVITY FEED TO STORAGE
11212 PUMP TO STORAGE
11221 GRAVITY FEED TO TREATMENT
11222 PUMP TO TREATMENT
11311 STORE IN ELEVATED TANK
11312 STORE IN GROUND-LEVEL TANK
11321 STORE IN LINED BASIN RESERVOIR
11322 STORE IN EARTHEN RESERVOIR

Figure C-1. Structure and Matrix of Water Source

ii. Are all watersheds in surface water sources surveyed and under legal control with authority to prevent contamination from external sources? In the case of stream sources, does an early warning system exist to prevent intake of water which is beyond capability of removal by treatment? NO

f. Are there cross-connections to the finished water mains such as:

i. Special bypasses at pumps so that one pump could serve as a raw water or finished water pump? No

ii. Pump packing gland sealing water? No

iii. Other —

Model the reliability of components associated with a cross-connection and enter the reliability as a cross-connection potential in Appendices A and B.

MOUNTAIN SOURCE -- IMPOUNDMENT

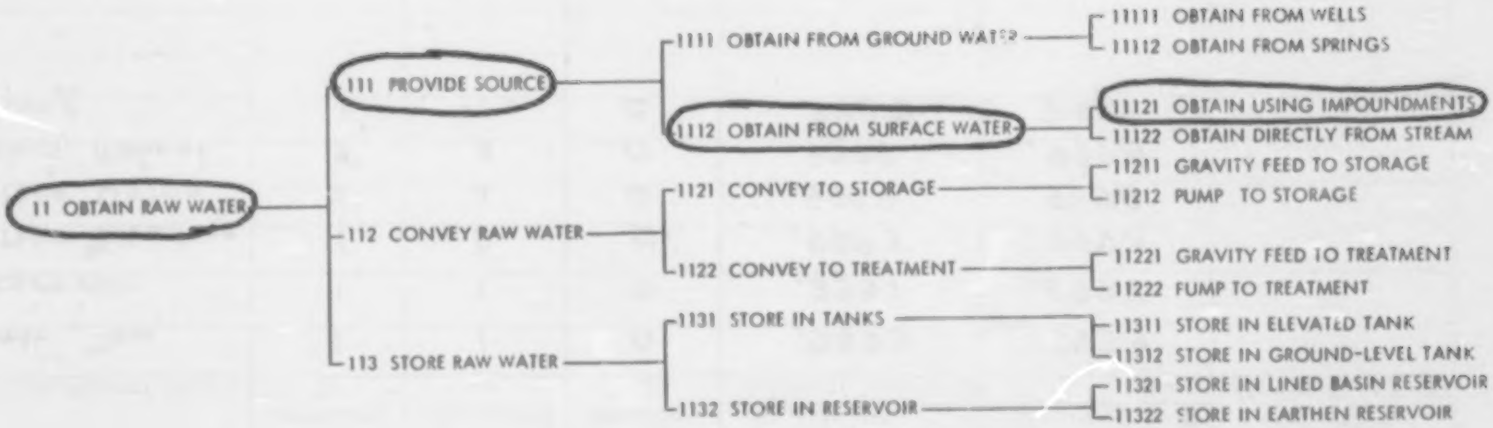
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Figure C-1. Structure and Matrix of Water Source

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Obtain Raw Water from Impoundment -- Mountain Impoundment

Stage Identification Number: 11121

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Earth Dam	1	1	0	,9993	,9993	
Reservoir	1	1	0	.9997	,9997	
Intake Structure	1	1	0	,9993	,9993	
Intake Gates	2	2	0	,9999	.9998	
Valves, Manual	2	2	0	.9999	.9998	
Piping	1	1	0	,9989	.9989	
Series Components Reliability = Product of R_i^N = R_1 =					.9968	—
Standby Components Reliability = Product of R_i = R_2 =						
Unit Operation Reliability, R = Product of $R_1 \times R_2$ = ___ x ___ = ___.9968						
Enter R in Column (5) of Table F-2.						

TABLE A-2. SUBSYSTEM RELIABILITY

Subsystem Description: Obtain Raw Water -- Mountain Impoundment

Stage Identification Number: 11

(1) Operation Identi-fication Number	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Unit Operation Reliability R_i	(6) If n=N, Compute R_i^N	(7) If n + s = N, enter R_i on curve R_1 in Fig. F-1, move horizontally to right, and read from R_2 or R_3 as appropriate for number of standbys
11121	1	1	0	.9968	.9968	—

Series Operations Reliability = Product of $R_i^N = R_1 =$ .9968 —

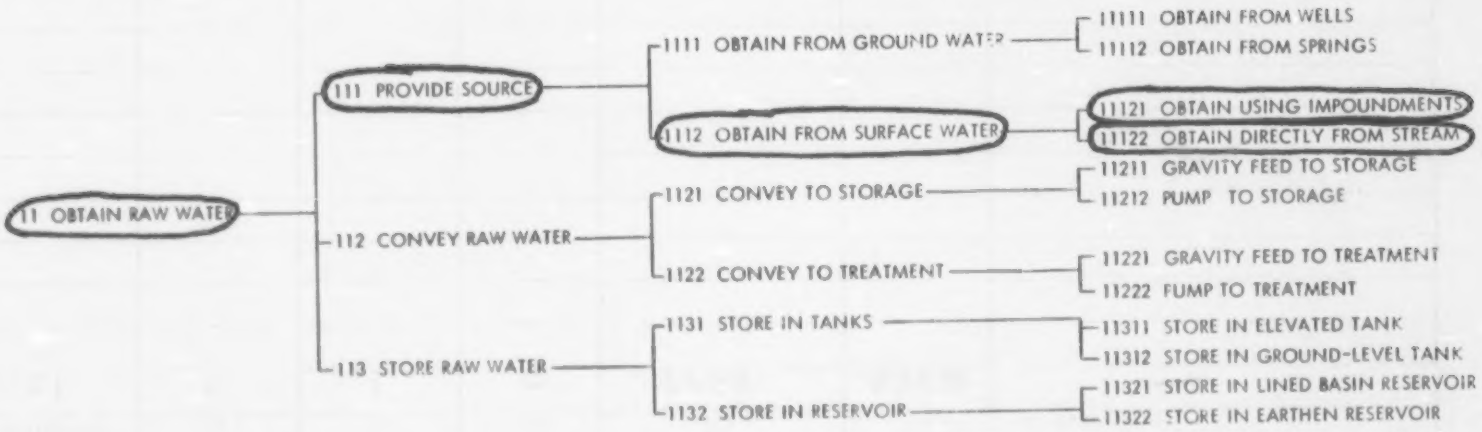
Standby Operations Reliability = Product of $R_i = R_2 =$

Subsystem Reliability = Product of $R_1 \times R_2 =$ .9968 x — = .9968 = R_{ss}

Subsystem Historical Water Supply Capability = 1.0 = B_{ss}

Subsystem Ability to Furnish Water = $R_{ss} \times B_{ss}$ .9968 x 1.0 = .9968.

MOUNTAIN SOURCE -- STREAM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11321 STORE IN LINED BASIN RESERVOIR
11322 STORE IN EARTHEN RESERVOIR

Figure C-1. Structure and Matrix of Water Source

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Obtain Using Impoundment .. Mountain Stream

Stage Identification Number: 11121

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Dam	1	1	0	.9993	.9993	
Piping	1	1	0	.9989	.9989	
					.996	—

Series Components Reliability = Product of $R_i^N = R_1 =$

Standby Components Reliability = Product of $R_i = R_2 =$

Unit Operation Reliability, R = Product of $R_1 \times R_2 =$ .996 x — = .996

Enter R in Column (5) of Table F-2.

TABLE A-2. SUBSYSTEM RELIABILITY

Subsystem Description: Obtain Raw Water -- Mountain Stream

Stage Identification Number: 11

(1) Operation Identification Number	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Unit Operation Reliability R_i	(6) If n=N, Compute R_i^N	(7) If n + s = N, enter R_i on curve R_1 in Fig. F-1, move horizontally to right, and read from R_2 or R_3 as appropriate for number of standbys
11121	1	1	0	.996	.996	—

Series Operations Reliability = Product of $R_i^N = R_1 =$ .996

Standby Operations Reliability = Product of $R_i = R_2 =$ —

Subsystem Reliability = Product of $R_1 \times R_2 =$ .996 x — = .996 = R_{ss}

Subsystem Historical Water Supply Capability = 1.0 = B_{ss}

Subsystem Ability to Furnish Water = $R_{ss} \times B_{ss}$ .996 x 1.0 = .996.

CREEK SOURCE

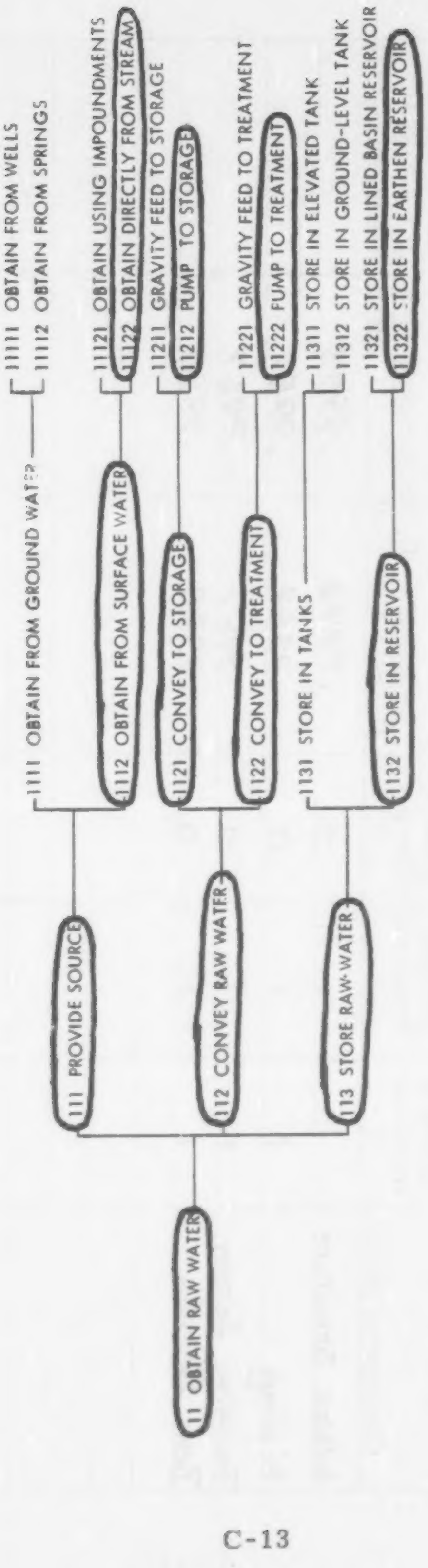
11 OBTAIN RAW WATER
111 PROVIDE SOURCE
112 CONVEY RAW WATER
113 STORE RAW WATER
1111 OBTAIN FROM GROUND WATER
1112 OBTAIN FROM SURFACE WATER
1121 CONVEY TO STORAGE
1122 CONVEY TO TREATMENT
1131 STORE IN TANKS
1132 STORE IN RESERVOIR
11111 OBTAIN FROM WELLS
11112 OBTAIN FROM SPRINGS
11121 OBTAIN USING IMPOUNDMENTS
11122 OBTAIN DIRECTLY FROM STREAM
11211 GRAVITY FEED TO STORAGE
11212 PUMP TO STORAGE
11221 GRAVITY FEED TO TREATMENT
11222 PUMP TO TREATMENT
11311 STORE IN ELEVATED TANK
11312 STORE IN GROUND-LEVEL TANK
11321 STORE IN LINED BASIN RESERVOIR
11322 STORE IN EARTHEN RESERVOIR

Figure C-1. Structure and Matrix of Water Source

TABLE A-1.UNIT OPERATION RELIABILITY

Operation Description: Obtain Directly from Stream -- Creek Source

Stage Identification Number: 11122

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Intake Structure	1	1	0	.9993	.9993	
Piping	1	1	0	.9989	.9989	
Traveling Screen	1	1	0	.9967	.9967	
Bar Screen	1	1	0	.9998	.9998	

Series Components Reliability = Product of R_i^N = R_1 = .993 —

Standby Components Reliability = Product of R_i = R_2 =

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .993 x — = .993

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Pump to Storage Creek Source

Stage Identification Number: 11212

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Valves, Manual	2	2	0	.9999	.9998	—
Pump	1	1	0	.9987	.9987	—
Pipe	1	1	0	.9989	.9989	—
Series Components Reliability = Product of R_i^N = R_1 =					.997	—
Standby Components Reliability = Product of R_i = R_2 =						
Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .997 x — = .997						
Enter R in Column (5) of Table F-2.						

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Pump to Treatment   Creek Source

Stage Identification Number: 11222

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Manual Valves	3	3	0	.9999	.9997	—
Pumps	2	1	1	—	—	1-
Pump Strainers	2	1	1	—	—	1-

Series Components Reliability = Product of R_i^N = R_1 = .9997

Standby Components Reliability = Product of R_i = R_2 = 1-

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .9997 × 1- = .999

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Store in Earthen Reservoir -- Creek Source

Stage Identification Number: 11322

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N R (from Fig. F-2)	R^N	Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Reservoir	1	1	0	.9997	.9997	—
Intake Structure	1	1	0	.9993	.9993	—
Dam (Dike)	1	1	0	.9993	.9993	—
Fixed Screen	1	1	0	.9998	.9998	—
Pipe	1	1	0	.9989	.9989	
Series Components Reliability = Product of R_i^N = R_1 =					.994	—

Standby Components Reliability = Product of R_i = R_2 =

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .994 x — = .994

Enter R in Column (5) of Table F-2.

TABLE A-2. SUBSYSTEM RELIABILITY

Subsystem Description: Obtain Raw Water Creek Source

Stage Identification Number: 11

(1) Operation Identification Number	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Unit Operation Reliability R_i	(6) If n=N, Compute R_i^N	(7) If n + s = N, enter R_i on curve R_1 in Fig. F-1, move horizontally to right, and read from R_2 or R_3 as appropriate for number of standbys
11122	1	1	0	.993	.993	—
11212	1	1	0	.997	.997	—
11322	1	1	0	.994	.994	—
11222	1	1	0	.999	.999	—

Series Operations Reliability = Product of R_i^N = R_1 = .982

Standby Operations Reliability = Product of R_i = R_2 = —

Subsystem Reliability = Product of $R_1 \times R_2$ = .982 x — = .982 = R_{ss}

Subsystem Historical Water Supply Capability = 1.0 = B_{ss}

Subsystem Ability to Furnish Water = $R_{ss} \times B_{ss}$ .982 x 1.0 = .982

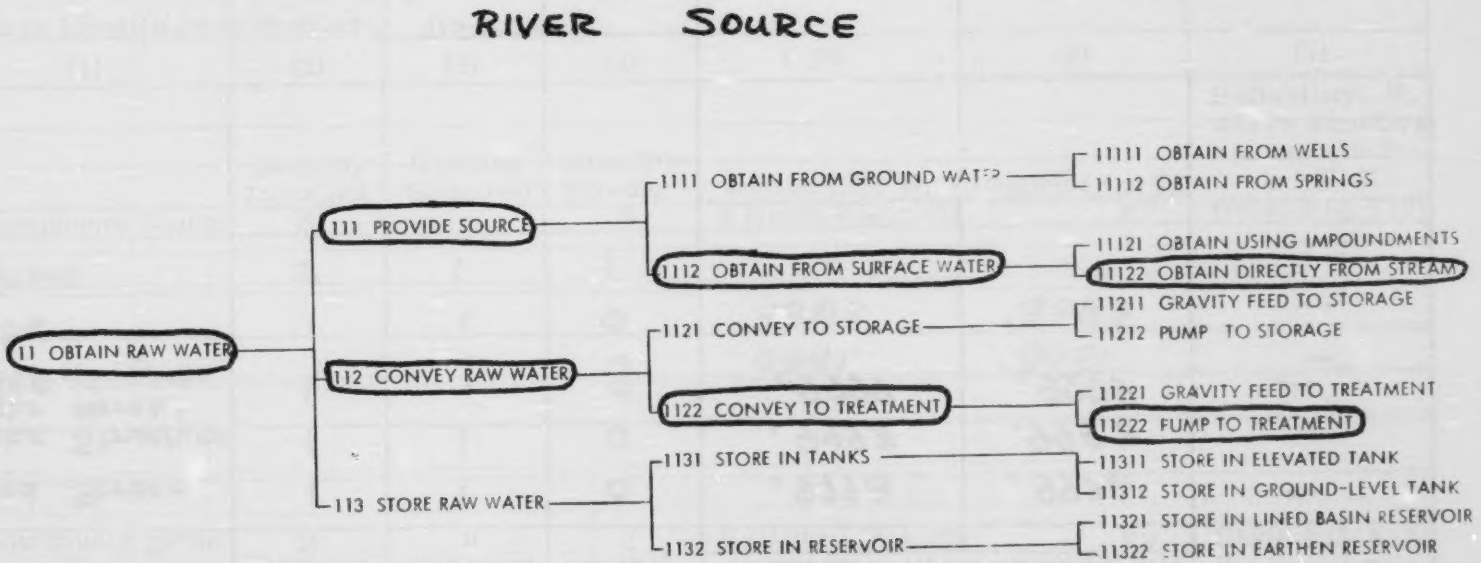
RIVER SOURCE
11 OBTAIN RAW WATER
111 PROVIDE SOURCE
112 CONVEY RAW WATER
113 STORE RAW WATER
1111 OBTAIN FROM GROUND WATER
1112 OBTAIN FROM SURFACE WATER
1121 CONVEY TO STORAGE
1122 CONVEY TO TREATMENT
1131 STORE IN TANKS
1132 STORE IN RESERVOIR
11111 OBTAIN FROM WELLS
11112 OBTAIN FROM SPRINGS
11121 OBTAIN USING IMPOUNDMENTS
11122 OBTAIN DIRECTLY FROM STREAM
11211 GRAVITY FEED TO STORAGE
11212 PUMP TO STORAGE
11221 GRAVITY FEED TO TREATMENT
11222 PUMP TO TREATMENT
11311 STORE IN ELEVATED TANK
11312 STORE IN GROUND-LEVEL TANK
11321 STORE IN LINED BASIN RESERVOIR
11322 STORE IN EARTHEN RESERVOIR

Figure C-1. Structure and Matrix of Water Source

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Obtain Directly from Stream -- River Source

Stage Identification Number: 11122

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N R (from Fig. F-2)	R^N	Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Fixed Screen	1	1	0	.9998	.9998	—
Intake Structure	1	1	0	.9993	.9993	—
Intake Manual Valve	1	1	0	.9999	.9999	—
Series Components Reliability = Product of $R_i^N = R_1$ =					.997	
Standby Components Reliability = Product of $R_i = R_2$ =						—

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .997 x — = .997

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Pump to Treatment -- River Source

Stage Identification Number: 11222

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Pump	2	1	1	–	–	1-
Pipe	1	1	0	.9989	.9989	–
Electric Power	1	1	0	.9991	.9991	–

Series Components Reliability = Product of R_i^N = R_1 = .997

Standby Components Reliability = Product of R_i = R_2 = 1-

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .997 x 1- = .997

Enter R in Column (5) of Table F-2.

TABLE A-2. SUBSYSTEM RELIABILITY

Subsystem Description: Obtain Raw Water -- River Source

Stage Identification Number: H

(1) Operation Identification Number	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Unit Operation Reliability R_i	(6) If n=N, Compute R_i^N	(7) If n + s = N, enter R_i on curve R_1 in Fig. F-1, move horizontally to right, and read from R_2 or R_3 as appropriate for number of standbys
11122	1	1	0	.997	.997	—
11222	1	1	0	.997	.997	—

Series Operations Reliability = Product of $R_i^N = R_1 =$ .983

Standby Operations Reliability = Product of $R_i = R_2 =$ —

Subsystem Reliability = Product of $R_1 \times R_2$ = .983 x — = .983 = R_{SS}

Subsystem Historical Water Supply Capability = 1.0 = B_{SS}

Subsystem Ability to Furnish Water = $R_{SS} \times B_{SS}$ .983 x 1.0 = .983.

TABLE A-5, OPERATION RELATIVE FAILURE EFFECT

OBTAIN RAW WATER

(1) Operation Number (From Table F-2)	(2) Failure Effect Weighting Factor, F (From Table F-4)	(3) Operation Weight Factor Fraction $1-(F_i \div \sum_{i=1}^{n} F_i)$	(4) Actual Operation Reliability, R_i (From Table F-2)	(5) Highest Operation Achievable Reliability, R_L	(6) Actual Operation Failure Effect (3) x (4)	(7) Lowest Operation Failure Effect (3) x (5)	(8) Operation Rating (6) ÷ (7)
11121 (IMP)	145152000	.974	.9968	.9999	.971	.973	.99
11121 (STR)	145152000	.974	.996	.999	.970	.973	.99
11122 (CREEK)	14515200	.997	.993	.999	.990	.996	.99
11212 (CREEK)	352800	.999	.997	.999	.996	.998	.99
11322 (CREEK)	3528	.999	.994	.999	.993	.998	.99
11222 (CREEK)	352800	.999	.999	.999	.998	.998	1.00
11122 (RIVER)	14515200	.997	.997	.999	.994	.996	1.00
11222 (RIVER)	352800	.999	.997	.999	.996	.998	1.00
App. C. C.3.d	256	.999	7/9	1.00	.777	.999	.78
App C. C.3.e.	14515200	.997	1/4	1.00	.249	.997	.25
							8.98
			$\frac{8.98}{10}$	= 89.8			

Summation, $\sum_{i=1}^{n} F_i$ 5726181153

Obtain Raw Water Sub- System Failure Effect Rating $\frac{\sum_{i=1}^{n} [(6) \div (7)]_i}{n}$ = .90

(sheet 1 of 2)

WATER CONSTITUENT DATA

Use Certified Laboratory Sources Only

Data Sources: Treatment Laboratory ✓ County Health Department ______ State Health Department ______

Water Supply System: Name Demonstration System

Location ______

Data for: Raw Water ✓ Treated Water ______ Distributed Water ______ Mountain Impoundment

Constituent	Public Health Service Drinking Water Standards Recommended Limit, X_1	Mandatory Limit, X_2	Laboratory Water Test Results $\bar{X}$ Mean	$\hat{s}$ Deviation	N, No. of Tests	95% Confidence Limits $\bar{X}' = \bar{X} + \frac{2\hat{s}}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\hat{s}}{\sqrt{n}}$	Z-Score Values $\frac{X_1 - \bar{X}'}{\hat{s}}$	$\frac{X_2 - \bar{X}'}{\hat{s}}$	$\frac{X_L - \bar{X}''}{\hat{s}}$	$\frac{X_1 - \bar{X}'}{\hat{s}}$	Probability of Exceeding DWS: Recommended Limit	Mandatory Limit
Nonremovables:										For Fluoride Only	For Fluoride Only		
Alkyl Benzene Sulfonate, ABS	0.5 mg/ℓ												
Arsenic, As	0.01	0.05 mg/ℓ											
Barium, Ba		1.0											
Cadmium, Cd		0.01											
Chromium, Hexavalent, Cr^{+6}		0.05											
Chloride, Cl	250.												
Copper, Cu	1.0												
Carbon Chloroform Extract, CCE	0.2												
Cyanide, CN	0.01	0.2											
Lead, pb		0.05											
Nitrate, NO_3	45.												
Selenium, Se		0.01											
Silver, Ag		0.05											
Sulfate, SO_4	250.												
Zinc, Zn	5.												
Radium -226		3µµc/ℓ											
Strontium-90		10µµc/ℓ											
Removables:													
Coliform	(a) X_1 or X_2: 10% + /month using 10 ml portions		22+	1.7+	23	2.88		-1.4					.92
	(b) ≥3 + (using 10 ml portions) in 2 consecutive samples in >1 sample when <20 samples/month, or >5% when ≥20 samples/month												
	(c) 1/100 ml avg/mo.; or >3/50 ml, >4/100 ml, 7/200 ml, 13/500 ml												
Color	15 units												

No other tests performed for this source. See summary sheet of tests on Mountain sources run by state health department.

Figure B-3. Calculations for Probability of Exceeding the Drinking Water Standards

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(sheet 1 of 2)

WATER CONSTITUENT DATA

Use Certified Laboratory Sources Only

Data Sources: Treatment Laboratory ✓ County Health Department ______ State Health Department ______

Water Supply System: Name Demonstration System

Location ______

Data for: Raw Water ✓ Treated Water ______ Distributed Water ______ Mountain Stream

	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Score Values				Probability of Exceeding DWS	
Constituent	Recommended Limit, X_1	Mandatory Limit, X_2	$\overline{X}$ Mean	σ Deviation	N, No. of Tests	95% Confidence Limits $\overline{X}' = \overline{X} + \frac{2\sigma}{\sqrt{n}}$	$\overline{X}'' = \overline{X} - \frac{2\sigma}{\sqrt{n}}$	$\frac{X_1 - \overline{X}'}{\sigma}$	$\frac{X_2 - \overline{X}'}{\sigma}$	$\frac{X_L - \overline{X}}{\sigma}$	$\frac{X_U - \overline{X}'}{\sigma}$	Recommended Limit	Mandatory Limit
Nonremovables:										For Fluoride Only	For Fluoride Only		
Alkyl Benzene Sulfonate, ABS	0.5 mg/ℓ												
Arsenic, As	0.01	0.05 mg/ℓ											
Barium, Ba		1.0											
Cadmium, Cd		0.01											
Chromium, Hexavalent, Cr^{+6}		0.05											
Chloride, Cl	250.												
Copper, Cu	1.0												
Carbon Chloroform Extract, CCE	0.2												
Cyanide, CN	0.01	0.2											
Lead, pb		0.05											
Nitrate, NO_3	45.												
Selenium, Se		0.01											
Silver, Ag		0.05											
Sulfate, SO_4	250.												
Zinc, Zn	5.												
Radium -226		3μμc/ℓ											
Strontium-90		10μμc/ℓ											
Removables:													
Coliform	(a) X_1 or X_2: 10% + /month using 10 ml portions		4.6+	0.6+	41	4.8		-7.1					1.00
	(b) ≥3 + (using 10 ml portions) in 2 consecutive samples in >1 sample when <20 samples/month, or >5% when ≥20 samples/month												
	(c) 1/100 ml avg/mo.; or >3/50 ml, >4/100 ml, 7/200 ml, 13/500 ml												
Color	15 units												

No other tests on this source. See tests on Mountain sources run by state department of health.

Figure B-3. Calculations for Probability of Exceeding the Drinking Water Standards

(sheet 1 of 2)

WATER CONSTITUENT DATA

Use Certified Laboratory Sources Only

Data Sources: Treatment Laboratory ________ County Health Department ________ State Health Department ✓

Water Supply System: Name Demonstration System

Location ________

Data for: Raw Water ✓ Treated Water ________ Distributed Water ________

Mountain Sources

Constituent	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Score Values				Probability of Exceeding DWS:	
	Recommended Limit, X_1	Mandatory Limit, X_2	$\bar{X}$ Mean	σ Deviation	N, No. of Tests	95% Confidence Limits $\bar{X}' = \bar{X} + \frac{2\sigma}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\sigma}{\sqrt{n}}$	$\frac{X_1 - \bar{X}'}{\sigma}$	$\frac{X_2 - \bar{X}'}{\sigma}$	$\frac{X_L - \bar{X}''}{\sigma}$	$\frac{X_1 - \bar{X}'}{\sigma}$	Recommended Limit	Mandatory Limit
Nonremovables:										For Fluoride Only	For Fluoride Only		
Alkyl Benzene Sulfonate, ABS	0.5 mg/ℓ												
Arsenic, As	0.01	0.05 mg/ℓ											
Barium, Ba		1.0											
Cadmium, Cd		0.01											
Chromium, Hexavalent, Cr^{+6}		0.05											
Chloride, Cl	250.		3.8	1.25	10	4.59		>10				0	
Copper, Cu	1.0												
Carbon Chloroform Extract, CCE	0.2												
Cyanide, CN	0.01	0.2											
Lead, pb		0.05											
Nitrate, NO_3	45.		.085	.08	10	.14		>10				0	
Selenium, Se		0.01											
Silver, Ag		0.05											
Sulfate, SO_4	250.							>10				0	
Zinc, Zn	5.												
Radium -226		3μμc/ℓ											
Strontium-90		10μμc/ℓ											
Removables:													
Coliform	(a) X_1 or X_2: 10% + /month using 10 ml portions												
	(b) ≥3 + (using 10 ml portions) in 2 consecutive samples in >1 sample when <20 samples/month, or >5% when ≥20 samples/month												
	(c) 1/100 ml avg/mo.; or >3/50 ml, >4/100 ml, 7/200 ml, 13/500 ml												
Color	15 units		5.4	2.8	10	7.20		2.78				.005	

Figure B-3. Calculations for Probability of Exceeding the Drinking Water Standards

(sheet 2 of 2)

Mountain Sources

Constituent	Public Health Service Drinking Water Standards: Recommended Limit, X_1	Public Health Service Drinking Water Standards: Mandatory Limit, X_2	Laboratory Water Test Results: $\bar{X}$ Mean	$\hat{\sigma}$ Deviation	N, No. of Tests	$\bar{X}' = \bar{X} + \frac{2\hat{\sigma}}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\hat{\sigma}}{\sqrt{n}}$	Z-Score Values: $\frac{X_1 - \bar{X}'}{\hat{\sigma}}$	$\frac{X_2 - \bar{X}'}{\hat{\sigma}}$	$\frac{X_L - \bar{X}''}{\hat{\sigma}}$	$\frac{X_U - \bar{X}'}{\hat{\sigma}}$	Probability of Exceeding DWS: Recommended Limit	Mandatory Limit
Removables (Cont'd)													
Fluoride, F	Avg. Temp.	F(LWR) X_L / F(Upper) X_U											
	50.0-53.7°F	0.9 / 1.7											
	53.8-58.3°F	0.8 / 1.5											
	58.4-63.8°F	0.8 / 1.3	.039	.06	6	.085	0			13	21	0 ~~1.00~~*	
	63.9-70.6°F	0.7 / 1.2											
	70.7-79.2°F	0.7 / 1.0											
	79.3-90.5°F	0.6 / 0.8											
Iron, Fe	0.3 mg/ℓ		.055	.029	11	.072		1.52				.07	
Manganese, Mn	0.5 mg/ℓ		.01	.03	6	.034		.53				.32	
Odor, Threshold Number	3												
Phenols	0.001 mg/ℓ												
Tastes	Not objectionable												
Total Dissolved Solids, TDS	500. mg/ℓ												
Turbidity	5 units		5.5	2.7	11	7.14		-.79				.78	

[†] In 2 consecutive samples, or in >1 sample when <20 samples/month, or in >5% of samples when >20 samples/month.

Control Characteristics Measurement (Treated and Distributed Water)

Aluminum	0.05 mg/ℓ												
Chlorine Residual	0.4 mg/ℓ												
Hardness	80 mg/ℓ												
Ph	X_L X_U 5.6 9.5												

* $P(F \leqq 0.8) = 1.00$, $P(F \geqq 1.3) = 0$

Figure B-3 (Continued)

(sheet 1 of 2)

WATER CONSTITUENT DATA

Use Certified Laboratory Sources Only

Data Sources: Treatment Laboratory ✓ County Health Department ________ State Health Department ________

Water Supply System: Name Demonstration System

Location ________

Data for: Raw Water ✓ Treated Water ________ Distributed Water ________

Creek Source

Constituent	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Score Values				Probability of Exceeding DWS:	
	Recommended Limit, X_1	Mandatory Limit, X_2	$\bar{X}$ Mean	$\hat{\sigma}$ Deviation	N, No. of Tests	95% Confidence Limits $\bar{X}' = \bar{X} + \frac{2\hat{\sigma}}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\hat{\sigma}}{\sqrt{n}}$	$\frac{X_1 - \bar{X}'}{\hat{\sigma}}$	$\frac{X_2 - \bar{X}'}{\hat{\sigma}}$	$\frac{X_L - \bar{X}''}{\hat{\sigma}}$	$\frac{X_1 - \bar{X}'}{\hat{\sigma}}$	Recommended Limit	Mandatory Limit
Nonremovables:										For Fluoride Only	For Fluoride Only		
Alkyl Benzene Sulfonate, ABS	0.5 mg/ℓ												
Arsenic, As	0.01	0.05 mg/ℓ											
Barium, Ba		1.0											
Cadmium, Cd		0.01											
Chromium, Hexavalent, Cr^{+6}		0.05											
Chloride, Cl	250.												
Copper, Cu	1.0												
Carbon Chloroform Extract, CCE	0.2												
Cyanide, CN	0.01	0.2											
Lead, pb		0.05											
Nitrate, NO_3	45.												
Selenium, Se		0.01											
Silver, Ag		0.05											
Sulfate, SO_4	250.												
Zinc, Zn	5.												
Radium -226		3 μμc/ℓ											
Strontium-90		10 μμc/ℓ											
Removables:													
Coliform	(a) X_1 or X_2: 10% + /month using 10 ml portions		5+		29							1.00	
	(b) ≥3 + (using 10 ml portions) in 2 consecutive samples in >1 sample when <20 samples/month, or >5% when ≥20 samples/month												
	(c) 1/100 ml avg/mo.; or >3/50 ml, >4/100 ml, 7/200 ml, 13/500 ml												
Color	15 units												

Figure B-3. Calculations for Probability of Exceeding the Drinking Water Standards

(sheet 2 of 2)

Creek Source

Constituent	Public Health Service Drinking Water Standards: Recommended Limit, X_1	Public Health Service Drinking Water Standards: Mandatory Limit, X_2	Laboratory Water Test Results: $\bar{X}$ Mean	σ Deviation	N, No. of Tests	$\bar{X}' = \bar{X} + \frac{2\sigma}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\sigma}{\sqrt{n}}$	Z-Score Values: $\frac{X_1 - \bar{X}'}{\sigma}$	$\frac{X_2 - \bar{X}'}{\sigma}$	$\frac{X_L - \bar{X}''}{\sigma}$	$\frac{X_U - \bar{X}'}{\sigma}$	Probability of Exceeding DWS: Recommended Limit	Mandatory Limit
Removables (Cont'd)													
Fluoride, F	Avg. Temp.	F(LWR) X_L F (Upper) X_U											
	50.0-53.7°F	0.9 1.7											
	53.8-58.3°F	0.8 1.5											
	58.4-63.8°F	0.8 1.3											
	63.9-70.6°F	0.7 1.2											
	70.7-79.2°F	0.7 1.0											
	79.3-90.5°F	0.6 0.8											
Iron, Fe	0.3 mg/ℓ												
Manganese, Mn	0.5 mg/ℓ												
Odor, Threshold Number	3												
Phenols	0.001 mg/ℓ												
Tastes	Not objectionable												
Total Dissolved Solids, TDS	500. mg/ℓ		33.2	10	37	36.5		-3.15				.9991	
Turbidity	5 units												

*In 2 consecutive samples, or in >1 sample when <20 samples/month, or in >5% of samples when >20 samples/month.

Control Characteristics Measurement (Treated and Distributed Water)

Aluminum	0.05 mg/ℓ												
Chlorine Residual	0.4 mg/ℓ												
Hardness	80 mg/ℓ												
Ph	X_L X_U 5.6 9.5												

Figure B-3 (Continued)

(sheet 1 of 2)

WATER CONSTITUENT DATA

Use Certified Laboratory Sources Only

Data Sources: Treatment Laboratory ______ County Health Department ______ State Health Department ✓

Water Supply System: Name Demonstration System
Location ______

Data for: Raw Water ✓ Treated Water ______ Distributed Water ______

Creek Source

Constituent	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Score Values				Probability of Exceeding DWS:	
	Recommended Limit, X_1	Mandatory Limit, X_2	$\bar{X}$ Mean	$\hat{s}$ Deviation	N, No. of Tests	95% Confidence Limits $\bar{X}'=\bar{X}+\frac{2\hat{s}}{\sqrt{n}}$	95% Confidence Limits $\bar{X}''=\bar{X}-\frac{2\hat{s}}{\sqrt{n}}$	$\frac{X_1-\bar{X}'}{\hat{s}}$	$\frac{X_2-\bar{X}}{\hat{s}}$	$\frac{X_L-\bar{X}''}{\hat{s}}$	$\frac{X_1-\bar{X}'}{\hat{s}}$	Recommended Limit	Mandatory Limit
Nonremovables:										For Fluoride Only	For Fluoride Only		
Alkyl Benzene Sulfonate, ABS	0.5 mg/ℓ												
Arsenic, As	0.01	0.05 mg/ℓ											
Barium, Ba		1.0											
Cadmium, Cd		0.01											
Chromium, Hexavalent, Cr^{+6}		0.05											
Chloride, Cl	250.	✓										0	
Copper, Cu	1.0												
Carbon Chloroform Extract, CCE	0.2												
Cyanide, CN	0.01	0.2											
Lead, pb		0.05											
Nitrate, NO_3	45.	✓										0	
Selenium, Se		[illegible]1											
Silver, Ag		0.[illegible]											
Sulfate, SO_4	250.												
Zinc, Zn	5.												
Radium -226		3µµc/ℓ											
Strontium-90		10µµc/ℓ											
Removables:													
Coliform	(a) X_1 or X_2: 10% + /month using 10 ml portions												
	(b) ≥3 + (using 10 ml portions) in 2 consecutive samples in >1 sample when <20 samples/month, or >5% when ≥20 samples/month												
	(c) 1/100 ml avg/mo.; or >3/50 ml, >4/100 ml, 7/200 ml, 13/500 ml												
Color	15 units		16.7	24.5	6	36.6		-.88				.81	

Figure B-3. Calculations for Probability of Exceeding the Drinking Water Standards

(sheet 2 of 2)

Creek Source

Constituent	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Score Values				Probability of Exceeding DWS:	
	Recommended Limit, X_1	Mandatory Limit, X_2	$\bar{X}$ Mean	σ Deviation	N, No. of Tests	$\bar{X}' = \bar{X} + \frac{2\sigma}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\sigma}{\sqrt{n}}$	$\frac{X_1 - \bar{X}'}{\sigma}$	$\frac{X_2 - \bar{X}'}{\sigma}$	$\frac{X_L - \bar{X}''}{\sigma}$	$\frac{X_U - \bar{X}'}{\sigma}$	Recommended Limit	Mandatory Limit
Removables (Cont'd)													
Fluoride, F	Avg. Temp. F(LWR) X_L	F(Upper) X_U											
	50.0-53.7°F 0.9	1.7											
	53.8-58.3°F 0.8	1.5											
	58.4-63.8°F 0.8	1.3											
	63.9-70.6°F 0.7	1.2											
	70.7-79.2°F 0.7	1.0											
	79.3-90.5°F 0.6	0.8											
Iron, Fe	0.3 mg/ℓ		.28	.08	6	.34		-.5				.935	
Manganese, Mn	0.5 mg/ℓ												
Odor, Threshold Number	3												
Phenols	0.001 mg/ℓ												
Tastes	Not objectionable												
Total Dissolved Solids, TDS	500. mg/ℓ	✓										0	
Turbidity	5 units		9.7	6	6	14.6		-1.6				.78	

*In 2 consecutive samples, or in >1 sample when <20 samples/month, or in >5% of samples when >20 samples/month.

Control Characteristics Measurement (Treated and Distributed Water)

Aluminum	0.05 mg/ℓ												
Chlorine Residual	0.4 mg/ℓ												
Hardness	80 mg/ℓ												
Ph	X_L X_U 5.6 9.5												

Figure B-3 (Continued)

(sheet 1 of 2)

WATER CONSTITUENT DATA

Use Certified Laboratory Sources Only
Data Sources: Treatment Laboratory ✓ County Health Department ______ State Health Department ______
Water Supply System: Name Demonstration System
Location ______
Data for: Raw Water ✓ Treated Water ______ Distributed Water ______

River Source

	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Score Values				Probability of Exceeding DWS:	
Constituent	Recommended Limit, X_1	Mandatory Limit, X_2	$\bar{X}$ Mean	$\hat{\sigma}$ Deviation	N, No. of Tests	95% Confidence Limits $\bar{X}' = \bar{X} + \frac{2\hat{\sigma}}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\hat{\sigma}}{\sqrt{n}}$	$\frac{X_1 - \bar{X}'}{\hat{\sigma}}$	$\frac{X_2 - \bar{X}'}{\hat{\sigma}}$	$\frac{X_L - \bar{X}''}{\hat{\sigma}}$	$\frac{X_1 - \bar{X}'}{\hat{\sigma}}$	Recommended Limit	Mandatory Limit
Nonremovables:										For Fluoride Only	For Fluoride Only		
Alkyl Benzene Sulfonate, ABS	0.5 mg/ℓ												
Arsenic, As	0.01	0.05 mg/ℓ											
Barium, Ba		1.0											
Cadmium, Cd		0.01											
Chromium, Hexavalent, Cr^{+6}		0.05											
Chloride, Cl	250.												
Copper, Cu	1.0												
Carbon Chloroform Extract, CCE	0.2												
Cyanide, CN	0.01	0.2											
Lead, pb		0.05											
Nitrate, NO_3	45.												
Selenium, Se		0.01											
Silver, Ag		0.05											
Sulfate, SO_4	250.												
Zinc, Zn	5.												
Radium -226		3μμc/ℓ											
Strontium-90		10μμc/ℓ											
Removables:													
Coliform	(a) X_1 or X_2: 10% + /month using 10 ml portions		5+		8							1.00	
	(b) ≥3 + (using 10 ml portions) in 2 consecutive samples in>1 sample when <20 samples/month, or >5% when ≥20 samples/month												
	(c) 1/100 ml avg/mo.; or >3/50 ml, >4/100 ml, 7/200 ml, 13/500 ml												
Color	15 units												

Figure B-3. Calculations for Probability of Exceeding the Drinking Water Standards

(sheet 2 of 2)

River Source

Constituent	Public Health Service Drinking Water Standards: Recommended Limit, X_1	Public Health Service Drinking Water Standards: Mandatory Limit, X_2	Laboratory Water Test Results: $\bar{X}$ Mean	σ Deviation	N, No. of Tests	$\bar{X}' = \bar{X} + \frac{2\sigma}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\sigma}{\sqrt{n}}$	Z-Score Values: $\frac{X_1 - \bar{X}'}{\sigma}$	$\frac{X_2 - \bar{X}'}{\sigma}$	$\frac{X_L - \bar{X}''}{\sigma}$	$\frac{X_U - \bar{X}'}{\sigma}$	Probability of Exceeding DWS: Recommended Limit	Mandatory Limit
Removables (Cont'd)													
Fluoride, F	Avg. Temp. F(LWR) X_L 50.0-53.7°F 0.9 53.8-58.3°F 0.8 58.4-63.8°F 0.8 63.9-70.6°F 0.7 70.7-79.2°F 0.7 79.3-90.5°F 0.6	F (Upper) X_U 1.7 1.5 1.3 1.2 1.0 0.8											
Iron, Fe	0.3 mg/ℓ												
Manganese, Mn	0.5 mg/ℓ												
Odor, Threshold Number	3												
Phenols	0.001 mg/ℓ												
Tastes	Not objectionable												
Total Disscived Solids, TDS	500. mg/ℓ												
Turbidity	5 units		30.7	15	28	36.4		-2.1				.98	

*In 2 consecutive samples, or in >1 sample when <20 samples/month, or in >5% of samples when >20 samples/month.

Control Characteristics Measurement (Treated and Distributed Water)

Aluminum	0.05 mg/ℓ												
Chlorine Residual	0.4 mg/ℓ												
Hardness	80 mg/ℓ												
Ph	X_L X_U 5.6 9.5												

Figure B-3 (Continued)

RAW WATER-- MOUNTAIN SOURCES

(1) Constituent	(2) Weight Factor	(3) 1-P(≥ DWS) P(≥ DWS) from Fig. G-3	(4) (2) x (3)	(5) $(2) \times (3) + \frac{\sum_{i=1}^{n} \lvert (2) \times (3) \rvert_i}{\sum_{i=1}^{n} (2)_i}$
Bacteria:				
Coliform	10	1.00	10.00	31.2
Physical:				
Turbidity	9	0.78	7.02	21.9
Color	9	0.003	0.027	0.1
Threshold Odor	9			
Taste	9			
Chemical, Recommended:				
ABS	9			
As	9			
Cl	9	0	0	0.0
Cu	9			
CCE	9			
CN	9			
Fe	9	0.07	0.63	2.0
Mn	9	0.32	2.88	9.0
NO_3	9	0	0	0.0
Phenols	9			
SO_4	9			
TDS	9			
Zn	9			
Chemical, Mandatory:				
As	10			
Ba	10			
Cd	10			
Cr^{+6}	10			
CN	10			
F	10	0	0	0.0
Pb	10			
Se	10			
Ag	10			
Radioactivity:				
Ra^{226}	10			
Sr^{90}	10			
	74	$\sum_{i=1}^{n} \lvert (2) \times (3) \rvert_i = 20.557$		
Mountain Sources Raw Water Rating =		$1 - \frac{\sum_{i=1}^{n} \lvert (2) \times (3) \rvert_i}{\sum_{i=1}^{n} (2)_i} = .72$		

Figure B-6. Rating of System Ability to Meet Constituent Limits of Public Health Service Drinking Water Standards of 1962

RAW WATER -- CREEK SOURCE

(1) Constituent	(2) Weight Factor	(3) 1 - P(≥ DWS) P(≥ DWS) from Fig. C-3	(4) (2) x (3)	(5) $(2)\times(3) \div \frac{\sum_{i=1}^{n}\lvert(2)\times(3)\rvert_i}{\sum_{i=1}^{n}(2)_i}$
Bacteria:				
Coliform	10	1.00	10.00	15.9
Physical:				
Turbidity	9	.99	8.91	16.2
Color	9	.81	7.29	13.3
Threshold Odor	9			
Taste	9			
Chemical, Recommended:				
ABS	9			
As	9			
Cl	9	0.00	0.00	0.0
Cu	9			
CCE	9			
CN	9			
Fe	9	0.935	8.415	15.5
Mn	9			
NO_3	9	0.00	0.00	0.0
Phenols	9			
SO_4	9			
TDS	9			
Zn	9			
Chemical, Mandatory:				
As	10			
Ba	10			
Cd	10			
Cr^{+6}	10			
CN	10			
F	10			
Pb	10			
Se	10			
Ag	10			
Radioactivity:				
Ra^{226}	10			
Sr^{90}	10			
	55		$\sum_{i=1}^{n}\lvert(2)\times(3)\rvert_i = 34.615$	
Creek source Raw Water Rating	=	$1 - \frac{\sum_{i=1}^{n}\lvert(2)\times(3)\rvert_i}{\sum_{i=1}^{n}(2)_i} = .37$		

Figure B-6. Rating of System Ability to Meet Constituent Limits of Public Health Service Drinking Water Standards of 1962

RAW-WATER -- RIVER SOURCE

(1) Constituent	(2) Weight Factor	(3) 1 - P(≥ DWS) P(≥ DWS) from Fig. G-3	(4) (2) x (3)	(5) $(2) \times (3) \div \frac{\sum_{i=1}^{n} \lvert(2) \times (3)\rvert_i}{\sum_{i=1}^{n} (2)_i}$
Bacteria:				
Coliform	10	1.00	10.00	10.1
Physical:				
Turbidity	9	0.98	8.82	8.0
Color	9			
Threshold Odor	9			
Taste	9			
Chemical, Recommended:				
ABS	9			
As	9			
Cl	9			
Cu	9			
CCE	9			
CN	9			
Fe	9			
Mn	9			
NO_3	9			
Phenols	9			
SO_4	9			
TDS	9			
Zn	9			
Chemical, Mandatory:				
As	10			
Ba	10			
Cd	10			
Cr^{+6}	10			
CN	10			
F	10			
Pb	10			
Se	10			
Ag	10			
Radioactivity:				
Ra^{226}	10			
Sr^{90}	10			
	19		$\sum_{i=1}^{n} \lvert(2) \times (3)\rvert_i$ = 18.82	
River Source Raw Water Rating =		1 −	$\frac{\sum_{i=1}^{n} \lvert(2) \times (3)\rvert_i}{\sum_{i=1}^{n} (2)_i}$ = 0.01	

Figure B-6. Rating of System Ability to Meet Constituent Limits of Public Health Service Drinking Water Standards of 1962

APPENDIX D

SURVEY OF RAW WATER TREATMENT

A. Water Treatment Capcity Data

1. Maximum present demand for water 4.8 MGD
In-plant requirements 0.4 MGD
Fire flow requirements, Table D-1 7.2 MGD
Total 12.4 MGD

2. Minimum daily storage between treatment and distribution system .62 million gallons

3. Minimum daily storage in the distribution system 2 million gallons

4. Total minimal daily storage, 2 + 3 = 2.62 million gallons

5. Flow from storage following treatment that can be delivered for fire flow duration,
(2 + 3) x (fire flow storage factor from Table D-1)= 6.3 MGD

TABLE D-1. REQUIRED FIRE FLOW[11]

Population	Required Fire Flow for Average City (gpm)	(MGD)	Duration (hr)	Storage Factor*
1,000	1,000	1.44	4	6.0
1,500	1,250	1.80	5	4.8
2,000	1,500	2.16	6	4.0
3,000	1,750	2.52	7	3.4
4,000	2,000	2.88	8	3.0
5,000	2,250	3.24	9	2.7
6,000	2,500	3.60	10	2.4
10,000	3,000	4.32	10	2.4
17,000	4,000	5.76	10	2.4
27,000	5,000	7.20	10	2.4
40,000	6,000	8.64	10	2.4
75,000	8.000	11.52	10	2.4
200,000	12,000	17.28	10	2.4

Over 200,000 population, 12,000 gpm, with 2,000 to 8,000 gpm additional for a second fire, for a 10-hour duration.
*Storage factor is ratio of total storage to MGD of fire flow.

6. Required treatment capacity at present is 1 - 5 = 6.1 MGD

7. Maximum demand ~~five years from present~~ 1980 7.9 MGD
Plant requirements 0.8 MGD
Fire flow requirements, Table B-1 8.6 MGD
Total 17.3 MGD

8. Storage in clearwell ~~five years from present~~ 1980 .62 million gallons

9. Distribution storage ~~five years from present~~ 1980 4 million gallons

10. Storage fire flow for duration, ~~five years from present~~ 1980 = (8 + 9)x(storage factor from Table D-1) = 11.1 MGD

11. Treatment capacity ~~five years from present~~ 1980 is 7 - 10 = 6.2 MGD

12. What is the rated capacity of the following operations:
Flocculations basins 5.5 MGD
Sedimentation basins 5.5 MGD
Sand and/or diatomite filters 5.5 MGD
~~Softening and/or iron-manganese removal~~ NA ~~MGD~~
~~Ion exchange softeners~~ - NA ~~MGD~~

13. Is the smallest rated capacity greater than the present required capacity? YES

14. What is the over-capacity (if any) of the operations with respect to the demand ~~five years from the present~~ 1980 (demand from 11 above)?

Flocculation basins $\frac{\text{Capacity}}{\text{Demand}}$ = .98

Sedimentation basins $\frac{\text{Capacity}}{\text{Demand}}$ = .98

Filters $\frac{\text{Capacity}}{\text{Demand}}$ = .98

~~Softeners $\frac{\text{Capacity}}{\text{Demand}}$ =~~ NA

~~Ion exchange softener $\frac{\text{Capacity}}{\text{Demand}}$ =~~ NA

15. If the demand exceeds capacity for an operation in 14 above, recompute using present demand:

NA

Flocculation basins Capacity/Demand = ________

Sedimentation basins Capacity/Demand= ________

Filters Capacity/Demand = ________

Softeners Capacity/Demand = ________

Ion exchange softener Capacity/Demand = ________

Note: Make a note in the rating summary that demand in five years exceeds present capacity and that present demands are used to rate the system.

16. Has water system ever discontinued or curtailed service to customers due to lack of treatment capacity? NO

a. Times per year 0

b. Days per time —

c. Calculate historical water treatment supply capability $B_t = \frac{365 - (\cancel{b \times a})^{0}}{365} = 1.0$

B. Water Treatment Reliability

1. Using the matrix of treatment operations in Figure D-1, detail each operation using the Tables from Appendix A and calculate the reliability and the failure effects of each operation and the subsystem. See page D-9 through D-38 for the demonstration system. The following must be considered in the computation of reliability

   a. Standby equipment for each operation where needed.

   b. In the case of the items in A. 14 with respect to standby redundancy, the following rules apply:

      For flocculation basins, sedimentation basins, and softeners, the redundancy is calculated by dividing the number of units by the ratios in

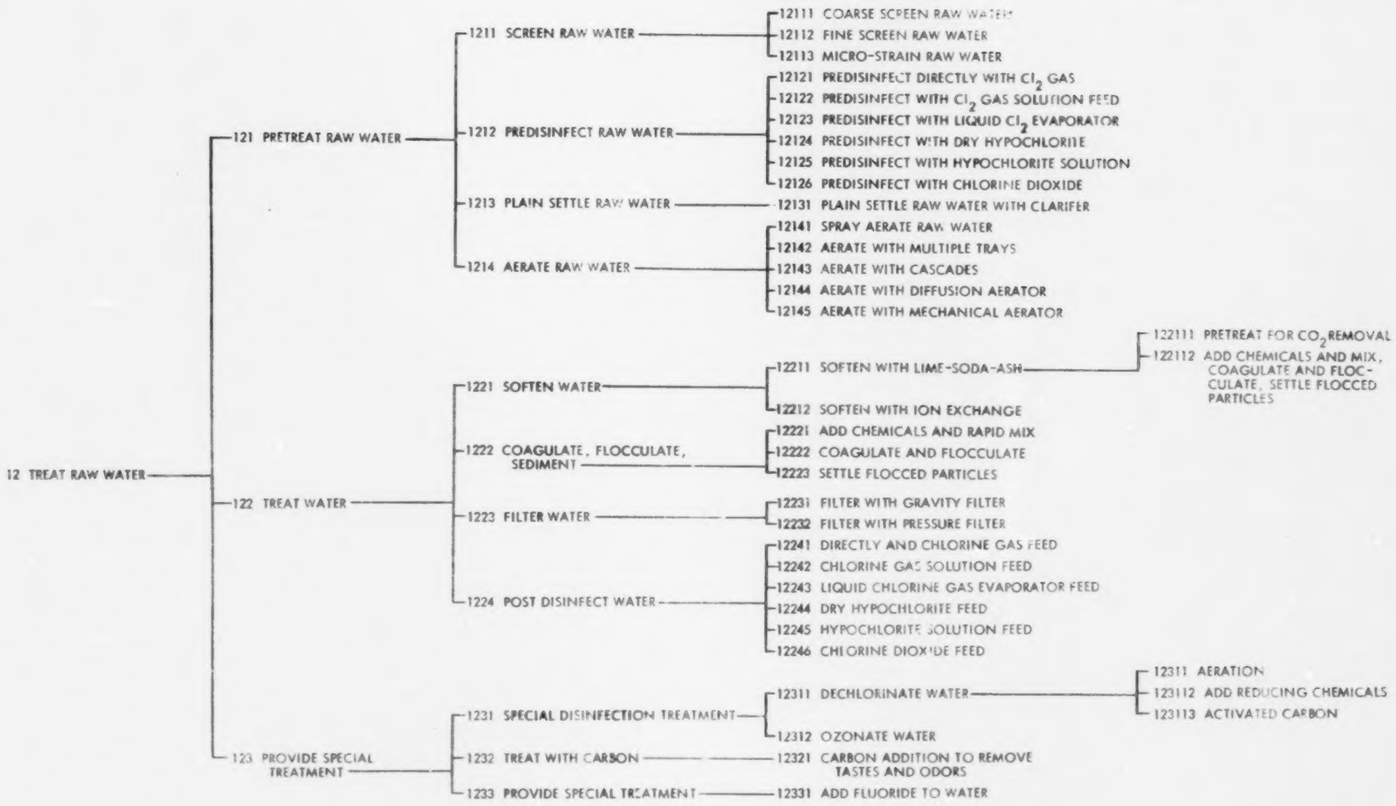

12 TREAT RAW WATER
121 PRETREAT RAW WATER
1211 SCREEN RAW WATER
12111 COARSE SCREEN RAW WATER
12112 FINE SCREEN RAW WATER
12113 MICRO-STRAIN RAW WATER
1212 PREDISINFECT RAW WATER
12121 PREDISINFECT DIRECTLY WITH Cl_2 GAS
12122 PREDISINFECT WITH Cl_2 GAS SOLUTION FEED
12123 PREDISINFECT WITH LIQUID Cl_2 EVAPORATOR
12124 PREDISINFECT WITH DRY HYPOCHLORITE
12125 PREDISINFECT WITH HYPOCHLORITE SOLUTION
12126 PREDISINFECT WITH CHLORINE DIOXIDE
1213 PLAIN SETTLE RAW WATER
12131 PLAIN SETTLE RAW WATER WITH CLARIFER
1214 AERATE RAW WATER
12141 SPRAY AERATE RAW WATER
12142 AERATE WITH MULTIPLE TRAYS
12143 AERATE WITH CASCADES
12144 AERATE WITH DIFFUSION AERATOR
12145 AERATE WITH MECHANICAL AERATOR
122 TREAT WATER
1221 SOFTEN WATER
12211 SOFTEN WITH LIME-SODA-ASH
122111 PRETREAT FOR CO_2 REMOVAL
122112 ADD CHEMICALS AND MIX, COAGULATE AND FLOCCULATE, SETTLE FLOCCED PARTICLES
12212 SOFTEN WITH ION EXCHANGE
1222 COAGULATE, FLOCCULATE, SEDIMENT
12221 ADD CHEMICALS AND RAPID MIX
12222 COAGULATE AND FLOCCULATE
12223 SETTLE FLOCCED PARTICLES
1223 FILTER WATER
12231 FILTER WITH GRAVITY FILTER
12232 FILTER WITH PRESSURE FILTER
1224 POST DISINFECT WATER
12241 DIRECTLY AND CHLORINE GAS FEED
12242 CHLORINE GAS SOLUTION FEED
12243 LIQUID CHLORINE GAS EVAPORATOR FEED
12244 DRY HYPOCHLORITE FEED
12245 HYPOCHLORITE SOLUTION FEED
12246 CHLORINE DIOXIDE FEED
123 PROVIDE SPECIAL TREATMENT
1231 SPECIAL DISINFECTION TREATMENT
12311 DECHLORINATE WATER
123111 AERATION
123112 ADD REDUCING CHEMICALS
123113 ACTIVATED CARBON
12312 OZONATE WATER
1232 TREAT WITH CARBON
12321 CARBON ADDITION TO REMOVE TASTES AND ODORS
1233 PROVIDE SPECIAL TREATMENT
12331 ADD FLUORIDE TO WATER

Figure D-1. Structure and Matrix for Raw Water Treatment, Subsystem 12

A. 14 and rounding up to the nearest whole number. The result is the number of required units; substracting required units from number of installed units gives redundancy or number of standby units. These should be used in conjunction with Figure A-2 or Table A-3.

2. Other Considerations for Rating Treatment System

a. Are there common walls between finished and lesser quality water? If yes, make the following calculations:

Quantity, n, of common walls = 3

Obtain reliability from Figure D-2 by entering n on the ordinate and reading reliability from the absicissa.

Reliability is 0.997

b. Are there interconnections to other treatment systems? If yes, compute system adequacy and reliability and enter here. NO *

Reliability is 0.—

Adequacy is 0.—

c. Can the treatment plant be bypassed? If yes, model the components that must fail in order to bypass treatment. Compute their availability and enter here as NO 0.—

* In an emergency situation, pipe can be laid to connect the city supply to that of a nearby military installation.

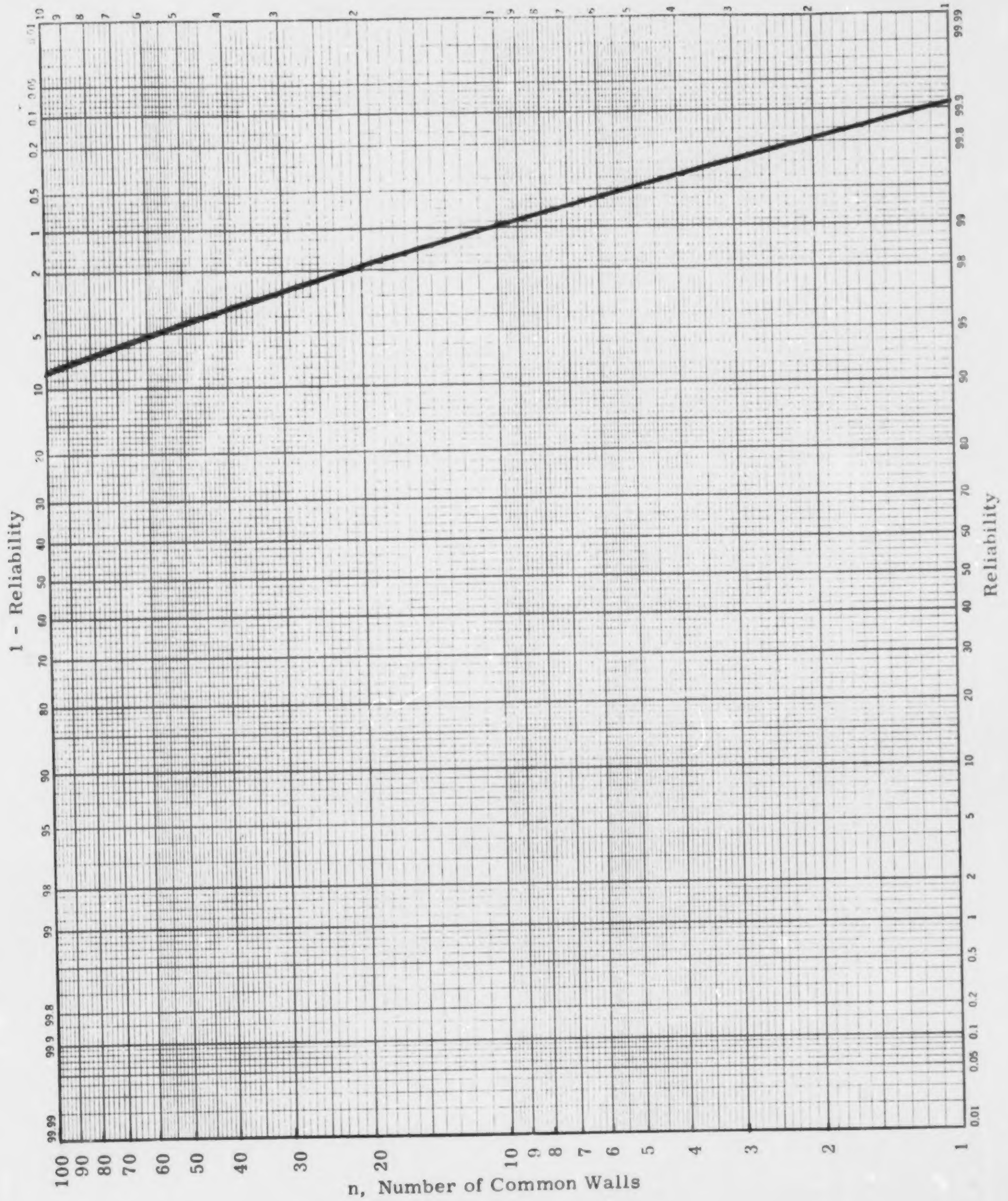


Figure D-2. Reliability of Common Walls for Finished and Lesser Quality Water

d. Indicate operating problems most often encountered.

Is special treatment provided?

Phenols ___ Yes ______ No ______

Taste and odor ✓ Yes ✓ No ______

Corrosive water ✓ Yes ✓ No ______

Short filter runs ✓ Yes ✓ No ______

Turbidity ✓ Yes ✓ No ______

Other, specify ______________________________

____

______________ Yes ______ No ______

Be sure all special treatment processes are included in model in B. 1 above.

e. Are there cross-connections of lesser and higher quality water in the treatment subsystem such as

i. Special bypasses at pumps to allow pumps to serve lesser quality water? NO

ii. Pump packing gland seal water? NO

iii. Chemical feeders? Yes

iv. Deicing equipment? Yes

v. Laboratory sampling lines and sinks? No

vi. Sanitary facilities? No

vii. Other? ______________________________

____

____

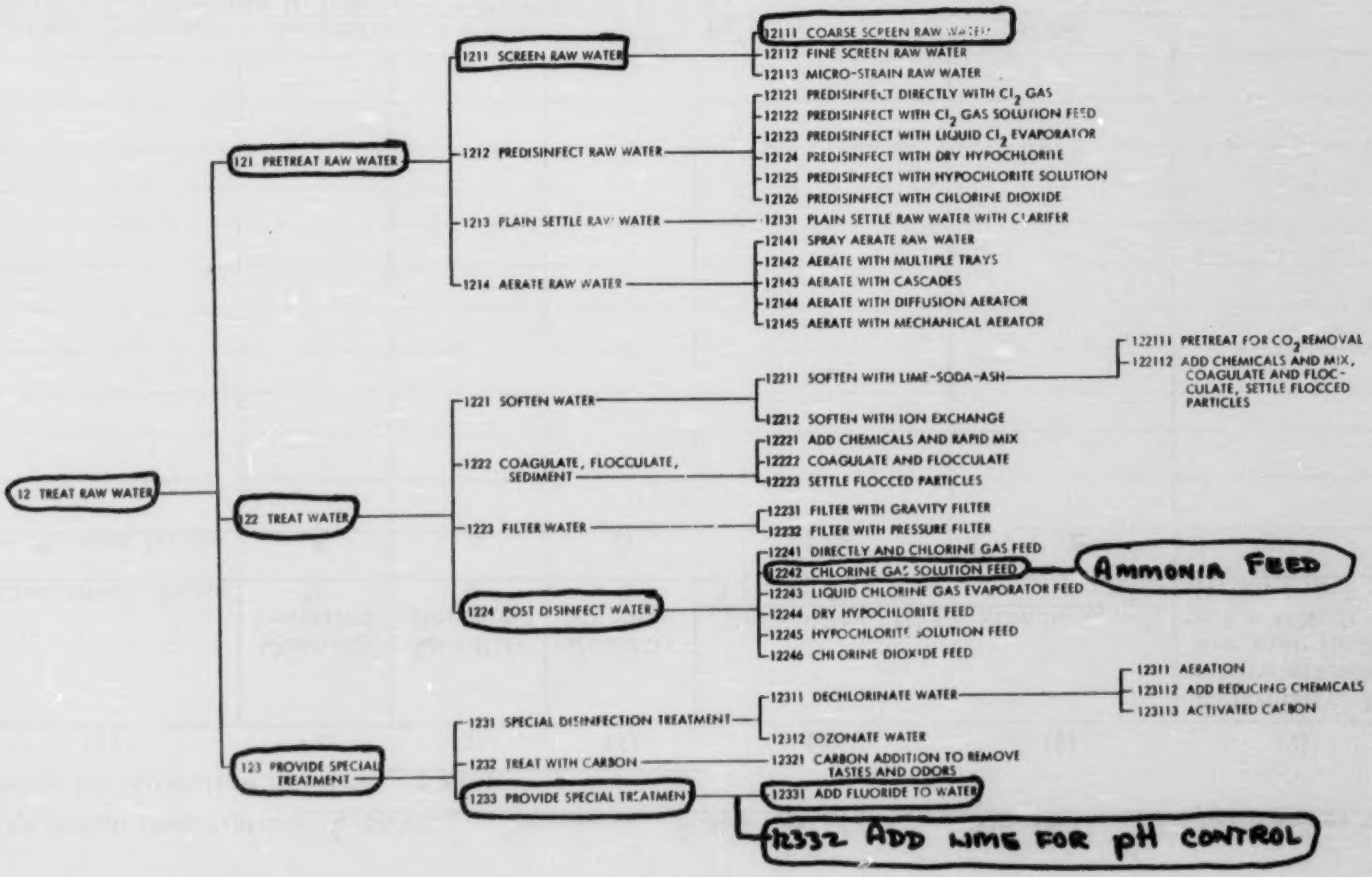
Model the reliability of components associated with a cross-connection and enter the reliability as a cross-connection potential into Appendix A and B.

f. Is adequate chlorine contact time allowed? Unless bacteriological or other tests indicate a need for maintaining a higher minimum concentration of residual chlorine, a minimum of at least 0.4 milligram of free chlorine per liter should be maintained in the treated water for an actual contact period of at least 30 minutes before delivery to the first consumer. If chloramine (combined chlorine) treatment is used for disinfection, the residual chlorine concentration as indicated by the orthotolidine method should be at least 2.0 milligrams per liter after at least three hours of contact before delivery to the first consumer. When required, the state health department should direct that the minimum concentration of residual chlorine, and the minimum retention period for the chlorinated water should be increased.[1]

g. Refer to the failure modes and effects analysis (Appendix I, Figure I-4) to determine effects of failure on system reliability. These effects are considered when modeling the system for reliability analysis.

C. Calculate the probability that treated water will exceed the constituent limits of the drinking water standards and the water quality rating for the subsystem using the procedures of Appendix B. See pages D-39 through D-45 for the demonstration system.

MOUNTAIN SOURCE -- IMPOUNDMENT


12 TREAT RAW WATER
121 PRETREAT RAW WATER
1211 SCREEN RAW WATER
12111 COARSE SCREEN RAW WATER
12112 FINE SCREEN RAW WATER
12113 MICRO-STRAIN RAW WATER
1212 PREDISINFECT RAW WATER
12121 PREDISINFECT DIRECTLY WITH Cl2 GAS
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12124 PREDISINFECT WITH DRY HYPOCHLORITE
12125 PREDISINFECT WITH HYPOCHLORITE SOLUTION
12126 PREDISINFECT WITH CHLORINE DIOXIDE
1213 PLAIN SETTLE RAW WATER
12131 PLAIN SETTLE RAW WATER WITH CLARIFER
1214 AERATE RAW WATER
12141 SPRAY AERATE RAW WATER
12142 AERATE WITH MULTIPLE TRAYS
12143 AERATE WITH CASCADES
12144 AERATE WITH DIFFUSION AERATOR
12145 AERATE WITH MECHANICAL AERATOR
122 TREAT WATER
1221 SOFTEN WATER
12211 SOFTEN WITH LIME-SODA-ASH
122111 PRETREAT FOR CO2 REMOVAL
122112 ADD CHEMICALS AND MIX, COAGULATE AND FLOCCULATE, SETTLE FLOCCED PARTICLES
12212 SOFTEN WITH ION EXCHANGE
1222 COAGULATE, FLOCCULATE, SEDIMENT
12221 ADD CHEMICALS AND RAPID MIX
12222 COAGULATE AND FLOCCULATE
12223 SETTLE FLOCCED PARTICLES
1223 FILTER WATER
12231 FILTER WITH GRAVITY FILTER
12232 FILTER WITH PRESSURE FILTER
1224 POST DISINFECT WATER
12241 DIRECTLY AND CHLORINE GAS FEED
12242 CHLORINE GAS SOLUTION FEED
AMMONIA FEED
12243 LIQUID CHLORINE GAS EVAPORATOR FEED
12244 DRY HYPOCHLORITE FEED
12245 HYPOCHLORITE SOLUTION FEED
12246 CHLORINE DIOXIDE FEED
123 PROVIDE SPECIAL TREATMENT
1231 SPECIAL DISINFECTION TREATMENT
12311 DECHLORINATE WATER
12311 AERATION
123112 ADD REDUCING CHEMICALS
123113 ACTIVATED CARBON
12312 OZONATE WATER
1232 TREAT WITH CARBON
12321 CARBON ADDITION TO REMOVE TASTES AND ODORS
1233 PROVIDE SPECIAL TREATMEN
12331 ADD FLUORIDE TO WATER
12332 ADD LIME FOR pH CONTROL

Figure D-1. Structure and Matrix for Raw Water Treatment, Subsystem 12

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Coarse Screen Raw Water -- Mountain Impoundment

Stage Identification Number: 12.1.1

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N R (from Fig. F-2)	 R^N	Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Bar Screen, Intake	2	2	0	.9998	.998	—

Series Components Reliability = Product of $R_i^N = R_1 =$ .998 —

Standby Components Reliability = Product of $R_i = R_2 =$

Unit Operation Reliability, R = Product of $R_1 \times R_2 =$ .998 x — = .998

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Chlorine Gas Solution Feed -- Mountain Impoundment

Stage Identification Number: 12242

NOTE: About 2 minutes contact time between chlorinator and first customer.

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Chlorinator *	2	1	1	.9973	—	.9999
Heater	1	1	0	.9903	.9903	—
Chlorine Bottles	9	2	7 **	.9996	.9992	—
Scales	2	2	0	Assume 1-	1-	—
Electric Power	1	1	0	.9991	.9991	—
Ammonia Feeder	1	1	0	.9973	.9973	—
Ammonia Bottles	3	1	2**	.9996	.9996	—

*If chlorinators or bottles fail, the probability of bacteriological contamination increases because continuous inspection/monitoring is not performed. P(coli E plus) x P(failure) = .92 x (1-.9999) = .000092 WHICH IS VERY SMALL.

**Bottles available but not connected; therefore, a true standby condition does not exist.

Series Components Reliability = Product of R_i^N = R_1 = .984

Standby Components Reliability = Product of R_i = R_2 = .9999

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .984 x .9999 = .984

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Add Fluoride to Water -- Mountain Impoundment

Stage Identification Number: 12331

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N: R (from Fig. F-2)	(6) Reliability, R, No Standbys, n=N: R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Fluoride Feeder	1	1	0	.9940	.9940	—
Fluoride Tank	2	1	1*	.9985	.9985	—
*Tank (drum) not connected; therefore, a standby does not truly exist.						
Series Components Reliability = Product of $R_i^N = R_1 =$					.9925	—
Standby Components Reliability = Product of $R_i = R_2 =$						
Unit Operation Reliability, R = Product of $R_1 \times R_2 =$ .9925 x — = .9925						
Enter R in Column (5) of Table F-2.						

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Add Lime for pH Control -- Mountain Impoundment

Stage Identification Number: 12332

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Lime Feeder	2	2	0	.9963	.9926	—
Float Level Controller	1	1	0	.9997	.9997	—
Flow Recorder	1	1	0	.9988	.9988	—

Series Components Reliability = Product of $R_i^N = R_1$ = .9911 —

Standby Components Reliability = Product of $R_i = R_2$ =

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .9911 x — = .9911

Enter R in Column (5) of Table F-2.

TABLE A-2. SUBSYSTEM RELIABILITY

Subsystem Description: Treat Raw Water -- Mountain Impoundment

Stage Identification Number: 12

(1) Operation Identification Number	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Unit Operation Reliability R_i	(6) If n=N, Compute R_i^N	(7) If n + s = N, enter R_i on curve R_1 in Fig. F-1, move horizontally to right, and read from R_2 or R_3 as appropriate for number of standbys
12111	1	1	0	.9998	.9998	—
12242	1	1	0	.984	.984	—
12331	1	1	0	.9925	.9925	—
12332	1	1	0	.9911	.9911	—

Series Operations Reliability = Product of $R_i^N = R_1 =$ .945

Standby Operations Reliability = Product of $R_i = R_2 =$ —

Subsystem Reliability = Product of $R_1 \times R_2 =$ .945 x — = .945 = R_{ss}

Subsystem Historical Water Supply Capability = 1.0 = Bss

Subsystem Ability to Furnish Water = $R_{ss} \times B_{ss} =$ .945 x 1.0 = .945.

MOUNTAIN SOURCE -- STREAM

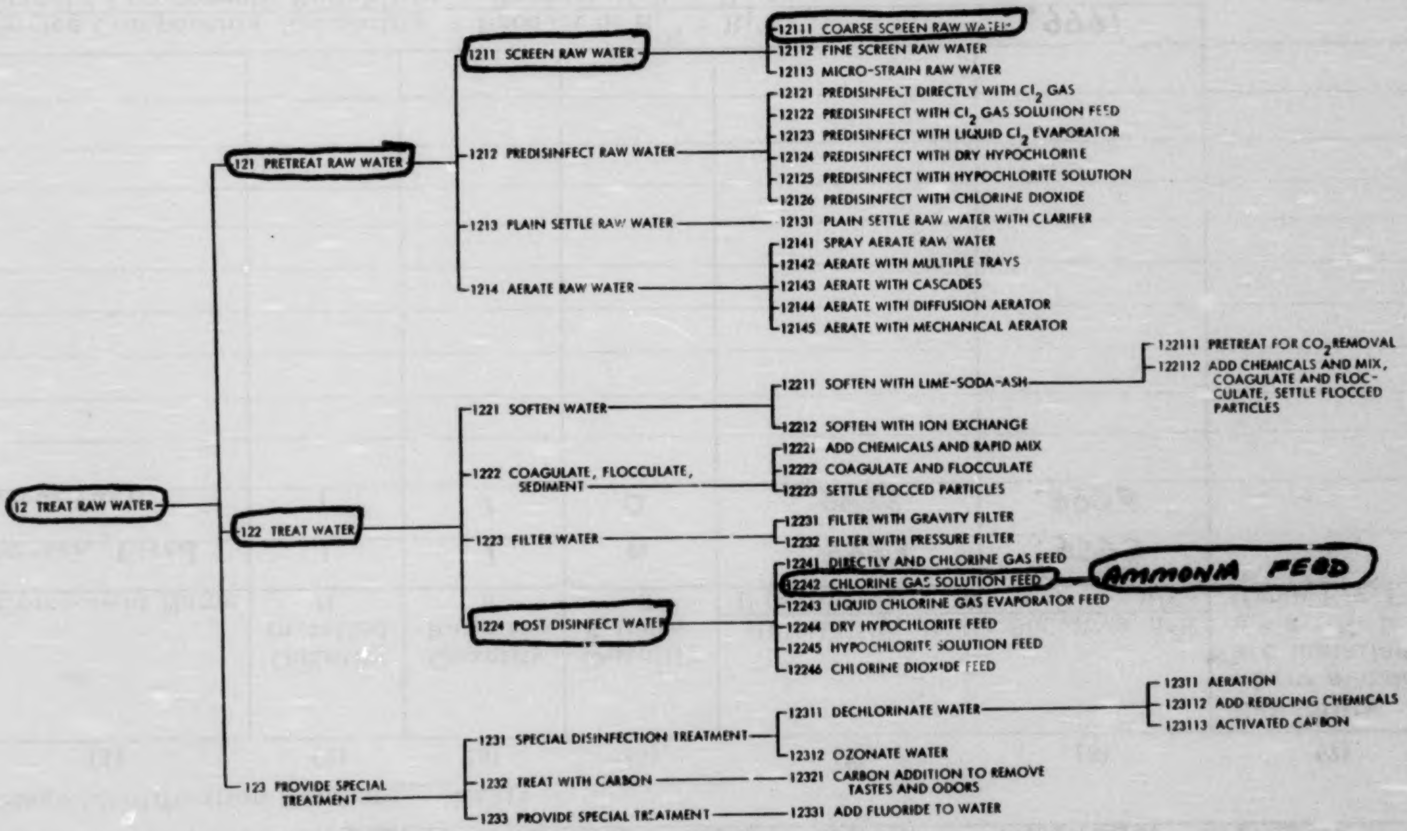
12 TREAT RAW WATER
121 PRETREAT RAW WATER
1211 SCREEN RAW WATER
12111 COARSE SCREEN RAW WATER
12112 FINE SCREEN RAW WATER
12113 MICRO-STRAIN RAW WATER
1212 PREDISINFECT RAW WATER
12121 PREDISINFECT DIRECTLY WITH Cl_2 GAS
12122 PREDISINFECT WITH Cl_2 GAS SOLUTION FEED
12123 PREDISINFECT WITH LIQUID Cl_2 EVAPORATOR
12124 PREDISINFECT WITH DRY HYPOCHLORITE
12125 PREDISINFECT WITH HYPOCHLORITE SOLUTION
12126 PREDISINFECT WITH CHLORINE DIOXIDE
1213 PLAIN SETTLE RAW WATER
12131 PLAIN SETTLE RAW WATER WITH CLARIFER
1214 AERATE RAW WATER
12141 SPRAY AERATE RAW WATER
12142 AERATE WITH MULTIPLE TRAYS
12143 AERATE WITH CASCADES
12144 AERATE WITH DIFFUSION AERATOR
12145 AERATE WITH MECHANICAL AERATOR
122 TREAT WATER
1221 SOFTEN WATER
12211 SOFTEN WITH LIME-SODA-ASH
122111 PRETREAT FOR CO_2 REMOVAL
122112 ADD CHEMICALS AND MIX, COAGULATE AND FLOCCULATE, SETTLE FLOCCED PARTICLES
12212 SOFTEN WITH ION EXCHANGE
1222 COAGULATE, FLOCCULATE, SEDIMENT
12221 ADD CHEMICALS AND RAPID MIX
12222 COAGULATE AND FLOCCULATE
12223 SETTLE FLOCCED PARTICLES
1223 FILTER WATER
12231 FILTER WITH GRAVITY FILTER
12232 FILTER WITH PRESSURE FILTER
1224 POST DISINFECT WATER
12241 DIRECTLY AND CHLORINE GAS FEED
12242 CHLORINE GAS SOLUTION FEED
AMMONIA FEED
12243 LIQUID CHLORINE GAS EVAPORATOR FEED
12244 DRY HYPOCHLORITE FEED
12245 HYPOCHLORITE SOLUTION FEED
12246 CHLORINE DIOXIDE FEED
123 PROVIDE SPECIAL TREATMENT
1231 SPECIAL DISINFECTION TREATMENT
12311 DECHLORINATE WATER
12311 AERATION
123112 ADD REDUCING CHEMICALS
123113 ACTIVATED CARBON
12312 OZONATE WATER
1232 TREAT WITH CARBON
12321 CARBON ADDITION TO REMOVE TASTES AND ODORS
1233 PROVIDE SPECIAL TREATMENT
12331 ADD FLUORIDE TO WATER

Figure D-1. Structure and Matrix for Raw Water Treatment, Subsystem 12

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Coarse Screen Raw Water -- Mountain Stream

Stage Identification Number: 12111

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Screen, Fixed	1	1	0	.9993	.9993	—
Structure	1	1	0	.9998	.9998	—

Series Components Reliability = Product of $R_i^N = R_1 =$ .9991 —

Standby Components Reliability = Product of $R_i = R_2 =$

Unit Operation Reliability, R = Product of $R_1 \times R_2 =$ .9991 x — = .9991

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Disinfect Water -- Mountain Stream

Stage Identification Number: 12242

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N R (from Fig. F-2)	R^N	Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Pipe	1	1	0	.9989	.9989	—
Chlorinator*	1	1	0	.9973	.9973	—
Chlorine Bottle*	1	1	0	.9996	.9996	—
Ammonia Feeder	1	1	0	.9973	.9973	—
Ammonia Bottles	1	1	0	.9996	.9996	—
Heater	1	1	0	.9903	.9903	—
*Chlorinator must be removed from service to change bottles. This results in						
$\frac{0.1 \times 10^6 \text{ G/D}}{(24^{\text{Hr}}/\text{D})(60 \text{ min/Hr})} \times .576$ MIN TO CHANGE BOTTLE = 40 Gallons of untreated water entering						
system each time a bottle must be changed.						
Series Components Reliability = Product of $R_i^N = R_1$ =					.983	—
Standby Components Reliability = Product of $R_i = R_2$ =						
Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .983 x — = .983						
Enter R in Column (5) of Table F-2.						

TABLE A-2. SUBSYSTEM RELIABILITY

Subsystem Description: Treat Raw Water -- Mountain Stream

Stage Identification Number: 12

(1) Operation Identification Number	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Unit Operation Reliability R_i	(6) If n=N, Compute R_i^N	(7) If n + s = N, enter R_i on curve R_1 in Fig. F-1, move horizontally to right, and read from R_2 or R_3 as appropriate for number of standbys
12111	1	1	0	.9991	.9991	—
12242	1	1	0	.983	.983	—

Series Operations Reliability = Product of R_i^N = R_1 = .982

Standby Operations Reliability = Product of R_i = R_2 = —

Subsystem Reliability = Product of $R_1 \times R_2$ = .982 x — = .982 = R_{SS}

Subsystem Historical Water Supply Capability = 1.0 = B_{SS}

Subsystem Ability to Furnish Water = $R_{SS} \times B_{SS}$ = .982 x 1.0 = .982.

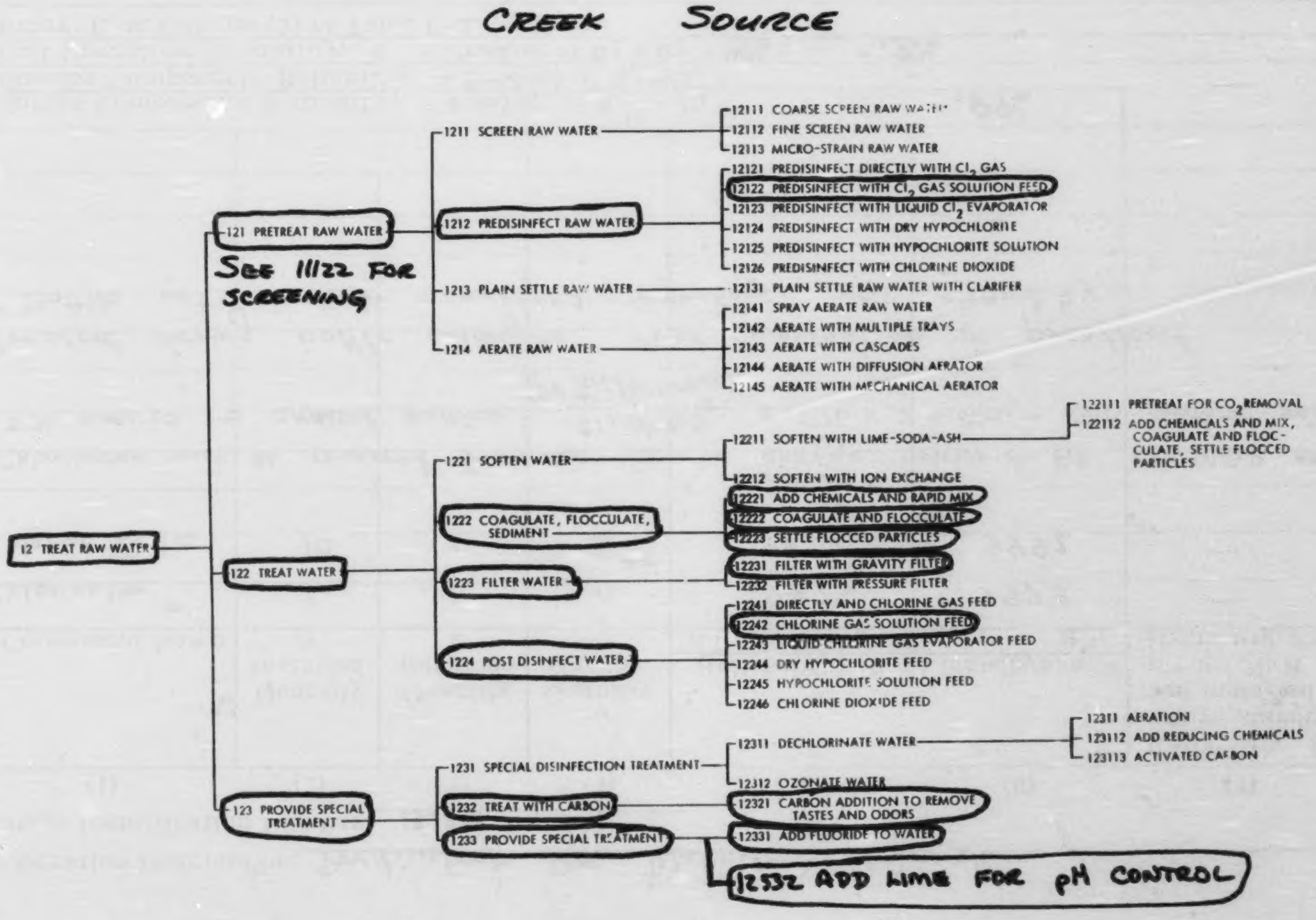
CREEK SOURCE
12 TREAT RAW WATER
121 PRETREAT RAW WATER
SEE 11122 FOR SCREENING
1211 SCREEN RAW WATER
12111 COARSE SCREEN RAW WATER
12112 FINE SCREEN RAW WATER
12113 MICRO-STRAIN RAW WATER
1212 PREDISINFECT RAW WATER
12121 PREDISINFECT DIRECTLY WITH Cl_2 GAS
12122 PREDISINFECT WITH Cl_2 GAS SOLUTION FEED
12123 PREDISINFECT WITH LIQUID Cl_2 EVAPORATOR
12124 PREDISINFECT WITH DRY HYPOCHLORITE
12125 PREDISINFECT WITH HYPOCHLORITE SOLUTION
12126 PREDISINFECT WITH CHLORINE DIOXIDE
1213 PLAIN SETTLE RAW WATER
12131 PLAIN SETTLE RAW WATER WITH CLARIFER
1214 AERATE RAW WATER
12141 SPRAY AERATE RAW WATER
12142 AERATE WITH MULTIPLE TRAYS
12143 AERATE WITH CASCADES
12144 AERATE WITH DIFFUSION AERATOR
12145 AERATE WITH MECHANICAL AERATOR
122 TREAT WATER
1221 SOFTEN WATER
12211 SOFTEN WITH LIME-SODA-ASH
122111 PRETREAT FOR CO_2 REMOVAL
122112 ADD CHEMICALS AND MIX, COAGULATE AND FLOCCULATE, SETTLE FLOCCED PARTICLES
12212 SOFTEN WITH ION EXCHANGE
1222 COAGULATE, FLOCCULATE, SEDIMENT
12221 ADD CHEMICALS AND RAPID MIX
12222 COAGULATE AND FLOCCULATE
12223 SETTLE FLOCCED PARTICLES
1223 FILTER WATER
12231 FILTER WITH GRAVITY FILTER
12232 FILTER WITH PRESSURE FILTER
1224 POST DISINFECT WATER
12241 DIRECTLY AND CHLORINE GAS FEED
12242 CHLORINE GAS SOLUTION FEED
12243 LIQUID CHLORINE GAS EVAPORATOR FEED
12244 DRY HYPOCHLORITE FEED
12245 HYPOCHLORITE SOLUTION FEED
12246 CHLORINE DIOXIDE FEED
123 PROVIDE SPECIAL TREATMENT
1231 SPECIAL DISINFECTION TREATMENT
12311 DECHLORINATE WATER
12311 AERATION
123112 ADD REDUCING CHEMICALS
123113 ACTIVATED CARBON
12312 OZONATE WATER
1232 TREAT WITH CARBON
12321 CARBON ADDITION TO REMOVE TASTES AND ODORS
1233 PROVIDE SPECIAL TREATMENT
12331 ADD FLUORIDE TO WATER
12332 ADD LIME FOR pH CONTROL

Figure D-1. Structure and Matrix for Raw Water Treatment, Subsystem 12

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Predisinfect Raw Water-- Creek

Stage Identification Number: 12122

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Chlorinator *	1	1	0	.9973	.9973	—
Chlorine Bottle	10	2	8**	.9996	.9992	—
					.996	—

*Chlorinator must be removed from service to change bottles. At .21 MGD and .576 MINUTES TO CHANGE Bottles, $\frac{.21 \times 10^6 \text{ G/D}}{(24 \text{ H/D})(60 \text{ min/HR})} \times .576 \times 2$ bottles = 168 gallons not treated during bottle changes. Post chlorination is practiced.

** Bottles not ~~hooked~~ connected; therefore, not stand by.

Series Components Reliability = Product of $R_i^N = R_1 =$ .996

Standby Components Reliability = Product of $R_i = R_2 =$ —

Unit Operation Reliability, R = Product of $R_1 \times R_2 =$ .996 × — = .996

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Add Chemicals, Rapid Mix, Coagulate, & Settle -- Creek

Stage Identification Number: 1222

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Lime Feeder	1	1	0	.9963	.9963	—
Alum Feeder	2	1	1	.9919	—	.9999
Carbon Feeder	2	1	1	.9989	—	.9999
Drain Valves	2	2	0	.9999	.9998	—
Mixing Tank	1	1	0	.9983	.9983	—
Sedimentation Basin	2	2	0	.9933	.993	—
Sluice Gates	4	4	0	.9999	.9996	—

NOTE: CROSS-CONNECTION POTENTIAL IN FEEDERS AND ON DE-ICERS ON SEDIMENTATION BASINS. PROBABILITY OF CROSS CONNECTION = $[(1-R \text{ of elevated tanks}) \times (1-R \text{ of distribution pumps})] \times [(1-R \text{ of check valve}) \times (1-R \text{ of manual valve})] = [(1-.9999) \times (1-.9999)] \times [(1-.9998) \times (1-.9999)] \approx 0$; Therefore, Reliabilility = 1-0 = 1

Series Components Reliability = Product of $R_i^N = R_1 =$ .987

Standby Components Reliability = Product of $R_i = R_2 =$ .9998

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .987 x .9998 = .986

Enter R in Column (5) of Table F-2.

TABLE A-1. OPERATION RELIABILITY

Operation Description: Filter with Gravity Filter -- Creek

Stage Identification Number: 12231

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Filter load ≈	1.5 GPM /FT²	; THEREFORE	HALF OF FILTERS ARE STANDBY!			
	6	3	3	—	—	1-
Manual Valves	4	4	0	.9999	.9996	—
Filter Sweeps	6	6	0	.9984	.992	—
Washwater Valves	6	6	0	.9996	.994	—
Pipe	1	1	0	.9989	.9989	—
Common wall with Clearwell	1	1	0	.999	.999	—

Series Components Reliability = Product of $R_i^N = R_1 =$ .985

Standby Components Reliability = Product of $R_i = R_2 =$ 1-

Unit Operation Reliability, R = Product of $R_1 \times R_2 =$ .985 x 1- = .985

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Post Disinfect Using Gas Solution Feed -- Creek

Stage Identification Number: 12242

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Chlorinator	2	1	1	—	—	.9999
Chlorine Bottle	1	1	0	.9996	.9996	—
NOTE: If both pre and post chlorinators fail at same time, contamination will occur. Probability of occurrence = {1-(.9973)(.999)(.9999)(.9996) = .006. Probability of contamination = (.006) [P(coli ≥ DWS*)] = (.006)(1.00) = .006 Reliability = 1-.006 = .994.						
* In raw water						
Series Components Reliability = Product of $R_i^N = R_1$ =					.9996	
Standby Components Reliability = Product of $R_i = R_2$ =						.9999
Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .9996 x .9999 = .9995						
Enter R in Column (5) of Table F-2.						

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Add Fluoride -- Creek

Stage Identification Number: 12331

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Fluoride Feeder	1	1	0	,9940	,9940	—
Fluoride Drum	1	1	0	,9985	,9985	—

Series Components Reliability = Product of R_i^N = R_1 = .992

Standby Components Reliability = Product of R_i = R_2 = —

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .992 x — = .992

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Add Lime to Control pH -- Creek

Stage Identification Number: 12332

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N: R (from Fig. F-2)	(6) Reliability, R, No Standbys, n=N: R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Lime Feeder	1	1	0	.9963	.9963	—

Series Components Reliability = Product of $R_i^N = R_1 =$ .9963 —

Standby Components Reliability = Product of $R_i = R_2 =$

Unit Operation Reliability, R = Product of $R_1 \times R_2 =$ .9963 x — = .9963

Enter R in Column (5) of Table F-2.

TABLE A-2. SUBSYSTEM RELIABILITY

Subsystem Description: Treat Raw Water -- Creek

Stage Identification Number: 12

(1) Operation Identification Number	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Unit Operation Reliability R_i	(6) If n=N, Compute R_i^N	(7) If n + s = N, enter R_i on curve R_1 in Fig. F-1, move horizontally to right, and read from R_2 or R_3 as appropriate for number of standbys
12122	1	1	0	.996	.996	—
1222	1	1	0	.986	.986	—
12231	1	1	0	.985	.985	—
12242	1	1	0	.999	.999	—
12331	1	1	0	.992	.992	—
12332	1	1	0	.996	.996	—
12321	Included	in 1222				
	12321 R = .999					

Series Operations Reliability = Product of R_i^N = R_1 = .922 —

Standby Operations Reliability = Product of R_i = R_2 =

Subsystem Reliability = Product of $R_1 \times R_2$ = .922 x — = .922 = R_{SS}

Subsystem Historical Water Supply Capability = 1.0 = B_{SS}

Subsystem Ability to Furnish Water = $R_{SS} \times E_{SS}$ = .922 x 1.0 = .922.

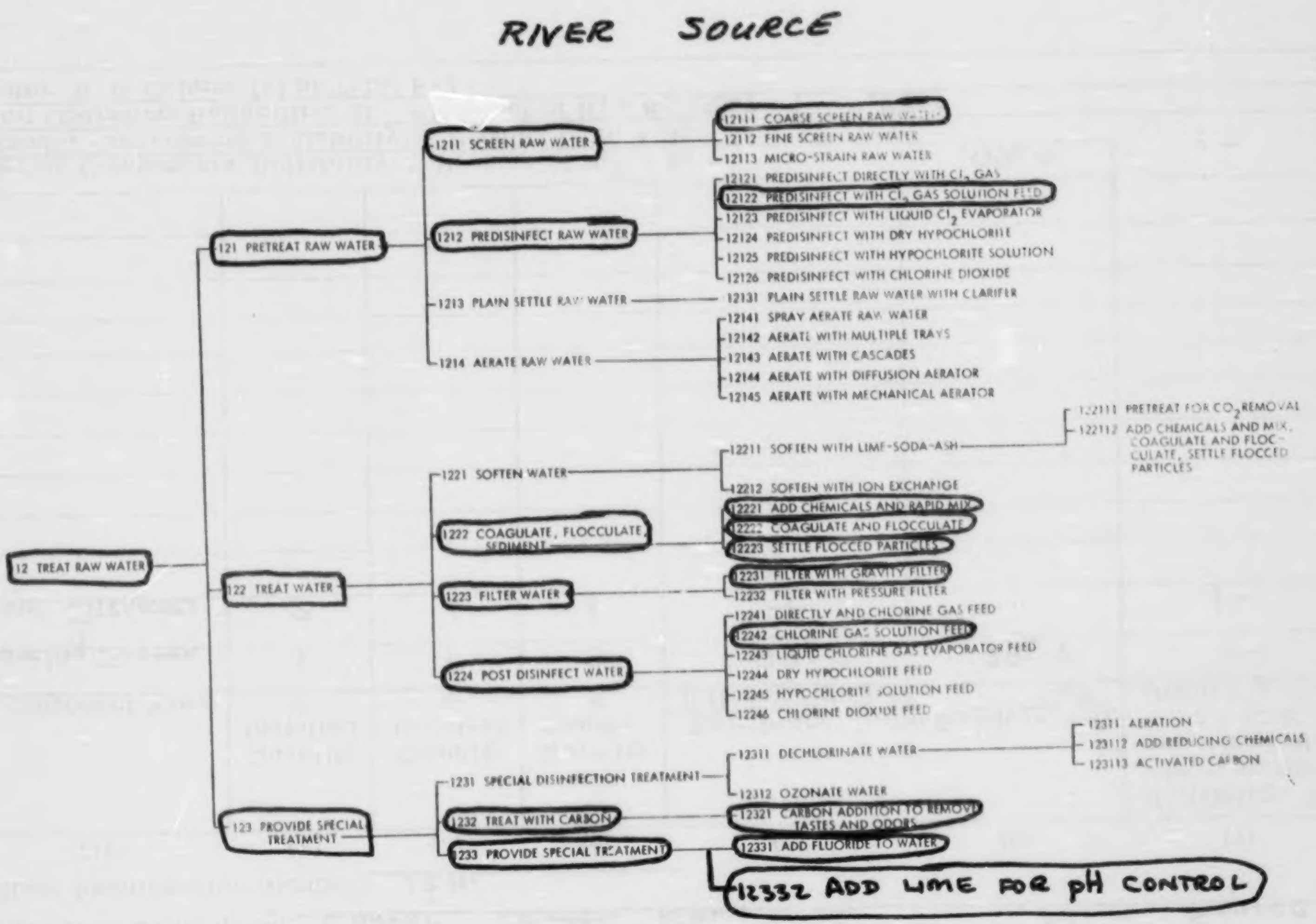
RIVER SOURCE
12 TREAT RAW WATER
121 PRETREAT RAW WATER
122 TREAT WATER
123 PROVIDE SPECIAL TREATMENT
1211 SCREEN RAW WATER
1212 PREDISINFECT RAW WATER
1213 PLAIN SETTLE RAW WATER
1214 AERATE RAW WATER
1221 SOFTEN WATER
1222 COAGULATE, FLOCCULATE, SEDIMENT
1223 FILTER WATER
1224 POST DISINFECT WATER
1231 SPECIAL DISINFECTION TREATMENT
1232 TREAT WITH CARBON
1233 PROVIDE SPECIAL TREATMENT
12111 COARSE SCREEN RAW WATER
12112 FINE SCREEN RAW WATER
12113 MICRO-STRAIN RAW WATER
12121 PREDISINFECT DIRECTLY WITH Cl_2 GAS
12122 PREDISINFECT WITH Cl_2 GAS SOLUTION FEED
12123 PREDISINFECT WITH LIQUID Cl_2 EVAPORATOR
12124 PREDISINFECT WITH DRY HYPOCHLORITE
12125 PREDISINFECT WITH HYPOCHLORITE SOLUTION
12126 PREDISINFECT WITH CHLORINE DIOXIDE
12131 PLAIN SETTLE RAW WATER WITH CLARIFER
12141 SPRAY AERATE RAW WATER
12142 AERATE WITH MULTIPLE TRAYS
12143 AERATE WITH CASCADES
12144 AERATE WITH DIFFUSION AERATOR
12145 AERATE WITH MECHANICAL AERATOR
12211 SOFTEN WITH LIME-SODA-ASH
122111 PRETREAT FOR CO_2 REMOVAL
122112 ADD CHEMICALS AND MIX, COAGULATE AND FLOCCULATE, SETTLE FLOCCED PARTICLES
12212 SOFTEN WITH ION EXCHANGE
12221 ADD CHEMICALS AND RAPID MIX
12222 COAGULATE AND FLOCCULATE
12223 SETTLE FLOCCED PARTICLES
12231 FILTER WITH GRAVITY FILTER
12232 FILTER WITH PRESSURE FILTER
12241 DIRECTLY AND CHLORINE GAS FEED
12242 CHLORINE GAS SOLUTION FEED
12243 LIQUID CHLORINE GAS EVAPORATOR FEED
12244 DRY HYPOCHLORITE FEED
12245 HYPOCHLORITE SOLUTION FEED
12246 CHLORINE DIOXIDE FEED
12311 DECHLORINATE WATER
12311 AERATION
123112 ADD REDUCING CHEMICALS
123113 ACTIVATED CARBON
12312 OZONATE WATER
12321 CARBON ADDITION TO REMOVE TASTES AND ODORS
12331 ADD FLUORIDE TO WATER
12332 ADD LIME FOR pH CONTROL

Figure D-1. Structure and Matrix for Raw Water Treatment, Subsystem 12

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TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Coarse Screen Raw Water ~ River Source

Stage Identification Number: 12111

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Traveling Screen	1	1	0	.9967	.9967	—
Pump Strainers	2	1	1	—	—	1–

Series Components Reliability = Product of $R_i^N = R_1 =$ .9967 1–

Standby Components Reliability = Product of $R_i = R_2 =$

Unit Operation Reliability, R = Product of $R_1 \times R_2 =$ .9967 x 1– = .9967

Enter R in Column (5) of Table F-2.

TABLE A-1, UNIT OPERATION RELIABILITY

Operation Description: Predisinfect with Chlorine Gas Solution Feed – River

Stage Identification Number: 12122

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Chlorinator	1	1	0	.9973	.9973	—
Chlorine Bottles	2	1	1	—	—	1–

Note: Service must be interrupted when changing bottles allowing $\frac{1\times10^6 \text{ G/D}}{24\frac{H}{D}\times60\frac{MIN}{H}}$ x .0001 x 24 x 60 = 100 gallons to pass without predisinfection; however, post disinfection is practiced.

Series Components Reliability = Product of R_i^N = R_1 = .9973

Standby Components Reliability = Product of R_i = R_2 = 1–

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .9973 x 1– = .9973

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Add Chemicals, Rapid Mix, Coagulate, Flocculate, Sediment -- River

Stage Identification Number: 1222

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Alum Feeder	1	1	0	.9919	.9919	—
NALCO Feeder	1	1	0	.9919	.9919	—
Agitator Mixer	1	1	0	.9987	.9987	—
Mix Basin	1	1	0	.9983	.9983	—
Flocculator	2	2	0	.9845	.9691	—
Settling Basin	2	2	0	.9983	.996	—
Pipe	1	1	0	.9989	.9989	—
Note: Deicer cross-connection. Probability of cross-connection occurrence same as for 1222 for Creek source ≈ 0.						

Series Components Reliability = Product of R_i^N = R_1 = .965

Standby Components Reliability = Product of R_i = R_2 = —

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .965 x — = .965

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Filter with Gravity Filter -- River

Stage Identification Number: 12231

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Filter	2	2	0	.9983	.996	—
Filter Sweeps	4	4	0	.9984	.992	—
Basin	2	2	0	.9983	.996	—
Control Valves	4	4	0	.9996	.996	—
Rate Controller	1	1	0	.9996	.9996	—
Manual Valve	2	2	0	.9999	.9999	—
Washwater Pumps	2	2	0	.9987	.996	—
Pipe	1	1	0	.9989	.9989	—
Common Wall with Clearwell	1	1	0	.9999	.9999	—
Common Wall with Raw Water	1	1	0	.9999	.9999	—
Series Components Reliability = Product of R_i^N = R_1 =					.973	—
Standby Components Reliability = Product of R_i = R_2 =						
Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .973 x — = .973						
Enter R in Column (5) of Table F-2.						

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Post Disinfect with Chlorine Gas Solution Feed -- River

Stage Identification Number: 12242

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Chlorinator	1	1	0	.9973	.9973	—
Chlorine Bottles	3	1	2	—	—	1–

NOTE: About 100 gallons of water pass without post chlorination each time a bottle is changed. If pre & post chlorinators fail, the P(coli ≥ DWS) would equal 100%. The probability of both failing at the same time equals 1 – (.9973)(.9973) = .008

Series Components Reliability = Product of R_i^N = R_1 = .9973

Standby Components Reliability = Product of R_i = R_2 = 1–

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .9973 x 1– = .9973

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Carbon Addition to Remove Taste, Odor, Turbidity - River

Stage Identification Number: 12321

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Carbon Feeder	1	1	0	.9989	.9989	—

Series Components Reliability = Product of $R_i^N = R_1 =$ .9989 —

Standby Components Reliability = Product of $R_i = R_2 =$

Unit Operation Reliability, R = Product of $R_1 \times R_2 =$ .9989 x — = .9989

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Adol Fluoride River

Stage Identification Number: 12331

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Fluoride Feeder	1	1	0	.9940	.9940	—
Fluoride Drum	1	1	0	.9985	.9985	—
Series Components Reliability = Product of $R_i^N = R_1$ =					.992	—
Standby Components Reliability = Product of $R_i = R_2$ =						
Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .992 x — = .992						
Enter R in Column (5) of Table F-2.						

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Add Lime to Control pH River

Stage Identification Number: 12332

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Lime Feeder	1	1	0	.9963	.9963	—
Lime Tank	1	1	0	.9985	.9985	—

Series Components Reliability = Product of R_i^N = R_1 = .994 —

Standby Components Reliability = Product of R_i = R_2 =

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .994 x — = .994

Enter R in Column (5) of Table F-2.

TABLE A-2. SUBSYSTEM RELIABILITY

Subsystem Description: Treat Raw Water River

Stage Identification Number: 12

(1) Operation Identification Number	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Unit Operation Reliability R_i	(6) If n=N, Compute R_i^N	(7) If n + s = N, enter R_i on curve R_1 in Fig. F-1, move horizontally to right, and read from R_2 or R_3 as appropriate for number of standbys
12111	1	1	0	.996	.996	—
12122	1	1	0	.997	.997	—
1222	1	1	0	.965	.965	—
12231	1	1	0	.973	.973	—
12242	1	1	0	.997	.997	—
12321	1	1	0	.998	.998	—
12331	1	1	0	.992	.992	—
12332	1	1	0	.994	.994	—

Series Operations Reliability = Product of R_i^N = R_1 = .921

Standby Operations Reliability = Product of R_i = R_2 = —

Subsystem Reliability = Product of $R_1 \times R_2$ = .921 x — = .921 = R_{SS}

Subsystem Historical Water Supply Capability = 1.0 = B_{SS}

Subsystem Ability to Furnish Water = $R_{SS} \times B_{SS}$ = .921 x 1.0 = .921.

TABLE A-5. OPERATION RELATIVE FAILURE EFFECT

TREAT RAW WATER

(1) Operation Number (From Table F-2)	(2) Failure Effect Weighting Factor, F (From Table F-4)	(3) Operation Weight Factor Fraction $1-(F_i \div \sum_{i=1}^{n} F_i)$	(4) Actual Operation Reliability, R_i (From Table F-2)	(5) Highest Operation Achievable Reliability, R_h	(6) Actual Operation Failure Effect (3) x (4)	(7) Lowest Operation Failure Effect (3) x (5)	(8) Operation Rating (6) ÷ (7)
12111(IMP)	16128	.999	.9998	.9999	.999	.998	1.00
12242(IMP)	1411200	.999	.984	.999	.983	.998	.98
12331(IMP)	176400	.999	.9925	.999	.991	.998	.99
12332(IMP)	1680	.999	.9911	.999	.987	.998	.99
12111 (STREAM)	16128	.999	.999	.999	.998	.998	1.00
12242(STREAM)	1411200	.999	.983	.999	.982	.998	.98
12122(CREEK)	1411200	.999	.996	.999	.995	.998	1.00
1222(CREEK)	508032000	.911	.986	.999	.898	.910	.99
12231(CREEK)	6350400	.998	.985	.999	.983	.997	.99
12242(CREEK)	1411200	.999	.999	.999	.998	.998	1.00
12321(CREEK)	3528	.999	.999	.999	.998	.998	1.00
12331(CREEK)	176400	.999	.992	.999	.991	.998	.99
12332(CREEK)	1680	.999	.996	.999	.995	.998	.99
12111(RIVER)	16128	.999	.996	.999	.995	.998	.99
12122(RIVER)	1411200	.999	.997	.999	.996	.998	.99
1222 (RIVER)	508032000	.911	.965	.999	.879	.910	.97
		(CONTINUED)					

Summation, $\sum_{i=1}^{n} F_i$ = ________

System Failure Effect Rating $\frac{\sum_{i=1}^{n} [(6) \div (7)]_i}{n}$ = ________

TABLE A-5. OPERATION RELATIVE FAILURE EFFECT

TREAT RAW WATER (CON'T)

(1) Operation Number (From Table F-2)	(2) Failure Effect Weighting Factor, F (From Table F-4)	(3) Operation Weight Factor Fraction $1-(F_i \div \sum_{i=1}^{n} F_i)$	(4) Actual Operation Reliability, R_i (From Table F-2)	(5) Highest Operation Achievable Reliability, R_{h}	(6) Actual Operation Failure Effect (3) x (4)	(7) Lowest Operation Failure Effect (3) x (5)	(8) Operation Rating (6) ÷ (7)
12231(RIVER)	6350400	.998	.973	.999	.971	.997	.97
12242(RIVER)	1411200	.999	.997	.999	.996	.998	1.00
12321(RIVER)	158760	.999	.998	.999	.997	.998	1.00
12331(RIVER)	176400	.999	.992	.999	.991	.998	.99
12332(RIVER)	1680	.999	.994	.999	.993	.998	.99
APP. D, 8.2	14515200	.997	.997	1.00	.994	.997	1.00
							21.80
			$\frac{21.80}{22} = .99$				

Summation, $\sum_{i=1}^{n} F_i$ = 372619453
FOR ENTIRE SYSTEM

Treat Raw Water Sub-System Failure Effect Rating $\frac{\sum_{i=1}^{n} [(6) \div (7)]_i}{n}$ = .99

(sheet 1 of 2)

WATER CONSTITUENT DATA

Use Certified Laboratory Sources Only
Data Sources: Treatment Laboratory ✓ County Health Department ______ State Health Department ______
Water Supply System: Name Demonstration System
Location ______

Data for: Raw Water ______ Treated Water ✓ Distributed Water ______ Mountain Impoundment

Constituent	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Score Values				Probability of Exceeding DWS:	
	Recommended Limit, X_1	Mandatory Limit, X_2	$\bar{X}$ Mean	$\hat{s}$ Deviation	N, No. of Tests	95% Confidence Limits $\bar{X}' = \bar{X} + \frac{2\hat{s}}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\hat{s}}{\sqrt{n}}$	$\frac{X_1 - \bar{X}'}{\hat{s}}$	$\frac{X_2 - \bar{X}}{\hat{s}}$	$\frac{X_L - \bar{X}''}{\hat{s}}$	$\frac{X_1 - \bar{X}'}{\hat{s}}$	Recommended Limit	Mandatory Limit
Nonremovables:													
Alkyl Benzene Sulfonate, ABS	0.5 mg/l									For Fluoride Only	For Fluoride Only		
Arsenic, As	0.01	0.05 mg/l											
Barium, Ba		1.0											
Cadmium, Cd		0.01											
Chromium, Hexavalent, Cr^{+6}		0.05											
Chloride, Cl	250.												
Copper, Cu	1.0												
Carbon Chloroform Extract, CCE	0.2												
Cyanide, CN	0.01	0.2											
Lead, pb		0.05											
Nitrate, NO_3	45.												
Selenium, Se		0.01											
Silver, Ag		0.05											
Sulfate, SO_4	250.												
Zinc, Zn	5.												
Radium -226		3μμc/l											
Strontium-90		10μμc/l											
Removables:													
Coliform	(a) X_1 or X_2: 10% + /month using 10 ml portions												
	(b) ≥3 + (using 10 ml portions) in 2 consecutive samples in >1 sample when <20 samples/month, or >5% when ≥20 samples/month												
	(c) 1/100 ml avg/mo.; or >3/50 ml, >4/100 ml, 7/200 ml, 13/500 ml												
Color	15 units												

NOTE: NO TESTS RUN OF TREATED WATER AT THE END OF TREATMENT AT THE MOUNTAIN STREAM SOURCE EXCEPT FOR pH.

Figure B-3. Calculations for Probability of Exceeding the Drinking Water Standards

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(sheet 2 of 2)

Treated Mountain Impoundment

Constituent	Public Health Service Drinking Water Standards: Recommended Limit, X_1	Public Health Service Drinking Water Standards: Mandatory Limit, X_2	Laboratory Water Test Results: $\bar{X}$ Mean	$\hat{\sigma}$ Deviation	N, No. of Tests	$\bar{X}' = \bar{X} + \frac{2\hat{\sigma}}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\hat{\sigma}}{\sqrt{n}}$	Z-Score Values: $\frac{X_1 - \bar{X}'}{\hat{\sigma}}$	$\frac{X_2 - \bar{X}'}{\hat{\sigma}}$	$\frac{X_L - \bar{X}''}{\hat{\sigma}}$	$\frac{X_U - \bar{X}'}{\hat{\sigma}}$	Probability of Exceeding DWS: Recommended Limit	Mandatory Limit
Removables (Cont'd)													
Fluoride, F	Avg. Temp. F(LWR) X_L	F (Upper) X_U											
	50.0-53.7°F 0.9	1.7											
	53.8-58.3°F 0.8	1.5											
	58.4-63.8°F 0.8	1.3											
	63.9-70.6°F 0.7	1.2											
	70.7-79.2°F 0.7	1.0											
	79.3-90.5°F 0.6	0.8											
Iron, Fe	0.3 mg/ℓ												
Manganese, Mn	0.5 mg/ℓ												
Odor, Threshold Number	3												
Phenols	0.001 mg/ℓ												
Tastes	Not objectionable												
Total Dissolved Solids, TDS	500. mg/ℓ												
Turbidity	5 units												

[†] In 2 consecutive samples, or in >1 sample when <20 samples/month, or in >5% of samples when >20 samples/month.

Control Characteristics Measurement (Treated and Distributed Water)

Aluminum	0.05 mg/ℓ												
Chlorine Residual	0.4 mg/ℓ												
Hardness	80 mg/ℓ												
Ph	X_L X_U 5.6 9.5		9.3	,235	31	9.38	9.22			-15.04	66.04	0	

Figure B-3 (Continued)

(sheet 1 of 2)

WATER CONSTITUENT DATA

Use Certified Laboratory Sources Only

Data Sources: Treatment Laboratory ✓ County Health Department ______ State Health Department ______

Water Supply System: Name Demonstration System

Location ______

Data for: Raw Water ______ Treated Water ✓ Distributed Water ______ Clearwell Creek Source

	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Score Values				Probability of Exceeding DWS:	
Constituent	Recommended Limit, X_1	Mandatory Limit, X_2	$\bar{X}$ Mean	$\hat{s}$ Deviation	N, No. of Tests	95% Confidence Limits $\bar{X}' = \bar{X} + \frac{2\hat{s}}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\hat{s}}{\sqrt{n}}$	$\frac{X_1 - \bar{X}'}{\hat{s}}$	$\frac{X_2 - \bar{X}}{\hat{s}}$	$\frac{X_L - \bar{X}''}{\hat{s}}$	$\frac{X_1 - \bar{X}'}{\hat{s}}$	Recommended Limit	Mandatory Limit
Nonremovables:										For Fluoride Only	For Fluoride Only		
Alkyl Benzene Sulfonate, ABS	0.5 mg/ℓ												
Arsenic, As	0.01	0.05 mg/ℓ											
Barium, Ba		1.0											
Cadmium, Cd		0.01											
Chromium, Hexavalent, Cr^{+6}		0.05											
Chloride, Cl	250.												
Copper, Cu	1.0												
Carbon Chloroform Extract, CCE	0.2												
Cyanide, CN	0.01	0.2											
Lead, pb		0.05											
Nitrate, NO_3	45.												
Selenium, Se		0.01											
Silver, Ag		0.05											
Sulfate, SO_4	250.												
Zinc, Zn	5.												
Radium -226		3μμc/ℓ											
Strontium-90		10μμc/ℓ											
Removables: Coliform	(a) X_1 or X_2: 10% + /month using 10 ml portions												
	(b) ≥3 + (using 10 ml portions) in 2 consecutive samples in >1 sample when <20 samples/month, or >5% when ≥20 samples/month												
	(c) 1/100 ml avg/mo.; or >3/50 ml, >4/100 ml, 7/200 ml, 13/500 ml												
Color	15 units												

Figure B-3. Calculations for Probability of Exceeding the Drinking Water Standards

(sheet 2 of 2)

Clearwell Creek Source

Constituent	Public Health Service Drinking Water Standards Recommended Limit, X_1	 Mandatory Limit, X_2	Laboratory Water Test Results $\bar{X}$ Mean	 σ Deviation	 N, No. of Tests	 $\bar{X}' = \bar{X} + \frac{2\sigma}{\sqrt{n}}$	 $\bar{X}'' = \bar{X} - \frac{2\sigma}{\sqrt{n}}$	Z-Score Values $\frac{X_1 - \bar{X}'}{\sigma}$	 $\frac{X_2 - \bar{X}'}{\sigma}$	 $\frac{X_L - \bar{X}''}{\sigma}$	 $\frac{X_U - \bar{X}'}{\sigma}$	Probability of Exceeding DWS: Recommended Limit	 Mandatory Limit
Removables (Cont'd)													
Fluoride, F	Avg. Temp.	F(LWR) X_L F(Upper) X_U											
	50.0-53.7°F	0.9 1.7	1.03	.085	36	1.06	1.00			-1.17	7.53		0 ~~.12~~*
	53.8-58.3°F	0.8 1.5											
	58.4-63.8°F	0.8 1.3											
	63.9-70.6°F	0.7 1.2											
	70.7-79.2°F	0.7 1.0											
	79.3-90.5°F	0.6 0.8											
Iron, Fe	0.3 mg/ℓ												
Manganese, Mn	0.5 mg/ℓ												
Odor, Threshold Number	3												
Phenols	0.001 mg/ℓ												
Tastes	Not objectionable												
Total Dissolved Solids, TDS	500. mg/ℓ												
Turbidity	5 units		1.06	.6	36	1.26		6.2				0	

†In 2 consecutive samples, or in >1 sample when <20 samples/month, or in >5% of samples when >20 samples/month.

Control Characteristics Measurement (Treated and Distributed Water)

Aluminum	0.05 mg/ℓ												
Chlorine Residual	0.4 mg/ℓ		1.33	.08	36		1.3			-11.6		1.00	
Hardness	80 mg/ℓ		100.7	9	36	103.7		-2.7				.996	
Ph	X_L X_U 5.5 9.5		7.9	.55	36	8.1	7.7			-3.8	2.5	.004 ~~1.00~~	

*P(F ≥ 1.7) = 0, P(F ≤ .9) = .12

Figure B-3 (Continued)

(sheet 1 of 2)

WATER CONSTITUENT DATA

Use Certified Laboratory Sources Only

Data Sources: Treatment Laboratory ✓ County Health Department ________ State Health Department ________

Water Supply System: Name Demonstration System

Location ________

Data for: Raw Water ________ Treated Water ✓ Distributed Water ________ Clearwell River Source

Constituent	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Score Values				Probability of Exceeding DWS:	
	Recommended Limit, X_1	Mandatory Limit, X_2	$\bar{X}$ Mean	$\hat{s}$ Deviation	N, No. of Tests	95% Confidence Limits $\bar{X}' = \bar{X} + \frac{2\hat{s}}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\hat{s}}{\sqrt{n}}$	$\frac{X_1 - \bar{X}'}{\hat{s}}$	$\frac{X_2 - \bar{X}'}{\hat{s}}$	$\frac{X_L - \bar{X}''}{\hat{s}}$	$\frac{X_1 - \bar{X}'}{\hat{s}}$	Recommended Limit	Mandatory Limit
Nonremovables:													
Alkyl Benzene Sulfonate, ABS	0.5 mg/ℓ									For Fluoride Only	For Fluoride Only		
Arsenic, As	0.01	0.05 mg/ℓ											
Barium, Ba		1.0											
Cadmium, Cd		0.01											
Chromium, Hexavalent, Cr^{+6}		0.05											
Chloride, Cl	250.												
Copper, Cu	1.0												
Carbon Chloroform Extract, CCE	0.2												
Cyanide, CN	0.01	0.2											
Lead, pb		0.05											
Nitrate, NO_3	45.												
Selenium, Se		0.01											
Silver, Ag		0.05											
Sulfate, SO_4	250.												
Zinc, Zn	5.												
Radium $^{-226}$		3μμc/ℓ											
Strontium^{-90}		10μμc/ℓ											
Removables:													
Coliform	(a) X_1 or X_2: 10% + /month using 10 ml portions												
	(b) ≥3 + (using 10 ml portions) in 2 consecutive samples in>1 sample when <20 samples/month, or >5% when ≥20 samples/month												
	(c) 1/100 ml avg/mo.; or >3/50 ml, >4/100 ml, 7/200 ml, 13/500 ml												
Color	15 units												

Figure B-3. Calculations for Probability of Exceeding the Drinking Water Standards

(sheet 2 of 2)

Clearwell River Source

Constituent	Public Health Service Drinking Water Standards: Recommended Limit, X_1	Public Health Service Drinking Water Standards: Mandatory Limit, X_2	Laboratory Water Test Results: $\bar{X}$ Mean	σ Deviation	N, No. of Tests	$\bar{X}' = \bar{X} + \frac{2\sigma}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\sigma}{\sqrt{n}}$	Z-Score Values: $\frac{X_1 - \bar{X}'}{\sigma}$	$\frac{X_2 - \bar{X}'}{\sigma}$	$\frac{X_L - \bar{X}''}{\sigma}$	$\frac{X_U - \bar{X}'}{\sigma}$	Probability of Exceeding DWS: Recommended Limit	Mandatory Limit
Removables (Cont'd)													
Fluoride, F	Avg. Temp.	F(LWR) X_L / F(Upper) X_U										0	
	50.0-53.7°F	0.9 / 1.7	1.04	.1	36	1.07	1.01			-1.1	6.3	.13*	
	53.8-58.3°F	0.8 / 1.5											
	58.4-63.8°F	0.8 / 1.3											
	63.9-70.6°F	0.7 / 1.2											
	70.7-79.2°F	0.7 / 1.0											
	79.3-90.5°F	0.6 / 0.8											
Iron, Fe	0.3 mg/l												
Manganese, Mn	0.5 mg/l												
Odor, Threshold Number	3												
Phenols	0.001 mg/l												
Tastes	Not objectionable												
Total Dissolved Solids, TDS	500. mg/l											0	
Turbidity	5 units		.61	.4	26	.77		5.7					

[†] In 2 consecutive samples, or in >1 sample when <20 samples/month, or in >5% of samples when >20 samples/month.

Control Characteristics Measurement (Treated and Distributed Water)

Aluminum	0.05 mg/l		.43	.15	22	.49	.39	-2.93				.9985 1 ~~[illegible]~~	
Chlorine Residual	0.4 mg/l		1.04	.1			1.27			17.2		0	
Hardness	80 mg/l		122.4	21.5	28	130.5		-2.35				.991	
Ph	X_L X_U 5.8 9.5		7.7	.4	28	7.85	7.55			4.9	4.4	0	

*P(F ≧ 1.7) = 0, P(F ≦ 0.9) = .13

Figure B-3.(Continued)

TREATED WATER

(1) Constituent	(2) Weight Factor	(3) 1-P(≥ DWS) P(≥ DWS) from Fig. G-3	(4) (2) x (3)	(5) $(2) \times (3) \div \frac{\sum_{i=1}^{n} \|(2) \times (3)\|_i}{\sum_{i=1}^{n} (2)_i}$
Bacteria:				
Coliform	10			
Physical:				
Turbidity	9			
Color	9			
Threshold Odor	9			
Taste	9			
Chemical, Recommended:				
ABS	9			
As	9			
Cl	9			
Cu	9			
CCE	9			
CN	9			
Fe	9			
Mn	9			
NO_3	9			
Phenols	9			
SO_4	9			
TDS	9			
Zn	9			
Chemical, Mandatory:				
As	10			
Ba	10			
Cd	10			
Cr^{+6}	10			
CN	10			
F	10			
Pb	10			
Se	10			
Ag	10			
Radioactivity:				
Ra^{226}	10			
Sr^{90}	10			
$\sum_{i=1}^{n} \|(2) \times (3)\|_i =$				
$\frac{\sum_{i=1}^{n} \|(2) \times (3)\|_i}{\sum_{i=1}^{n} (2)_i} =$ ______				

ONLY TWO TESTS PERFORMED; THEREFORE, RATING IS NOT CALCULATED. THE TESTS ARE FOR TURBIDITY AND FLUORIDE IN THE CLEARWELL.

Figure B-6. Rating of System Ability to Meet Constituent Limits of Public Health Service Drinking Water Standards of 1962

APPENDIX E

SURVEY OF TREATED WATER DISTRIBUTION

A. Distribution Data

1. Pump station

a. Quantity and Capacity

Pump No.	Capacity (MGD)
1- River	1.0
2- River	2.0
1- Creek	0.8
2- Creek	2.0
3- Creek	2.2
4 - Creek	3.2 (Spare)
Total: 6 pumps	8.0 (excluding spare)

b. What is maximum capacity available from discharge manifold? 5.5 MGD

c. During past five years, what was the maximum peak day demand for water? 5.7 MGD

d. During past five years what is nominal minimum daily storage on the distribution system (from Appendix D, paragraph A. 3)? 2 MGD

e. What is the rate of flow that can be delivered from storage on the distribution system for required fire flow duration (d x factor from Table D-1, Appendix D)? 4.8 MGD

f. Difference between c and e represents required pumping capacity = 0.9 MGD

g. Using these results, make a table of pumps required to achieve capacity and indicate standby pumps.

Pump Capacity	No. of Pumps	No. Required	No. Standby	
1 MGD	1	1	1	River
0.8 MGD	1	1	3	Creek

Note: Not included here is 0.6 MGD available from the two mountain sources as a gravity feed.

2. Where booster pump stations are used, list the following:

Area	Population (1000s)	Maximum Hr Demand (MGD)	Fire Flow (MGD)	Total	Booster Capacity	No. Pumps	No. Standby
1	—	0.16	0.16	0.32	0.32	2	1
2	—	0.02	0.02	0.04	0.04	2	1

3. Arterial and secondary feeder mains

a. With respect to arterial mains 40 years after installation: UNKNOWN

i. What is estimated consumer demand? ______ MGD

ii. Estimated fire flow demand? ______MGD

iii. Sum of i + ii = ______MGD

iv. What is estimated nominal minimum daily storage on the distribution system? ______million gallons

v. What is estimated rate of flow from distribution storage for the required fire flow duration |iv x storage factor from Table D-1, Appendix D| ? ______MGD

vi. Required capacity of arterial mains is iii - v = ______MGD

vii. What is ratio of installed arterial capacity to required capacity? ______

b. With respect to secondary feeder mains, size according to area served 40 years after installation. Use same method as A. 3 above, but apply to areas served. UNKNOWN

Area Served	Estimated Population	Required Capacity	Installed Capacity	Ratio Installed: Required

c. Length of installed mains and pipes of all sizes? 77 miles

d. Number and miles of alternate or duplicate mains to supply each area in case of a main or pipe break? ~~No.~~ ___, 67 miles

Number of mains or pipes having no duplicate supply? ~~No.~~ ___, 10 miles

e. Are pressures recorded at hours of peak demand where pressures are expected to be lowest? Yes

f. Do records show pressures at least 20 psi at critical points at hours of peak demand? Yes

If no, how many hours per year is pressure less than 20 psi? 0 hours

g. What is the shortest life expectancy of any segment of the system? UNKNOWN _____ years

h. What is expected life of material generally used for mains? 50 years

i. What is number of dead ends in system? 16

Are dead ends provided with protected blow-off valves for flushing? Yes -- Fire Hydrants

Is a flushing procedure followed? Yes

j. Are mains looped to form a grid and avoid dead ends? $\frac{1}{8}$ of system is not _____

k. Are all mains isolatable to small areas for repair purposes without interrupting flow to more than one block? $\frac{1}{8}$ of system is not _____

l. What percentage of the system has the following life expectancy?

Unknown

10 to 34 years _____ %

35 to 49 years _____ %

50 to 100 years 90 %*

Some parts of system exceed 145 years in age.

*Estimate

m. For mains 3 inches and smaller, what is the number of customers served? Do they fall within Table E-1? Indicate in Table. OK

n. Is a proper disinfection, flushing, and bacteriological testing procedure followed following repairs, alterations, or installations? Such a procedure should consist of: Yes -- Two repairs treated in 15 repairs made. All 15 were tested and showed no positives.

   i. Loading the main with water containing excessive (40 to 50 mg/ℓ) chlorine and allowing it to stand about 24 hours; after 24 hours a well-defined residual should remain.

   ii. Drain, flush with clean water, refill, and allow to stand a period of time.

   iii. Test for bacteriological organisms. If none are present, return to service or begin service.

o. Is a pressure testing program used to hydrostatically test mains for leaks? How many leaks are found per year? 156
141 CUSTOMER LINE LEAKS + 15 MAIN LEAKS

p. Is there a code prohibiting cross-connections to lesser or unknown quality water or other liquids? Plumbing Code Yes

q. Is there an active program to inspect for and eliminate cross-connections in the system? Only on new plumbing installations or plumbing alterations. How many cross-connections are found and eliminated per year (average)? 72

r. Is a valve (including hydrants) maintenance program practiced to ensure proper valve operation and good condition? Yes

s. Is chlorine residual maintained throughout distribution system? See paragraph f, page D-5. Yes

TABLE E-1. MAXIMUM NUMBER OF CUSTOMERS DESIRABLE ON SMALL MAINS

Pipe Diameter (inches)	Length of Main (feet)	Desirable Number of Customers				Actual Number of Customers				Ratios Desirable: Actual			
		Pressure at Start of Main (psi)				Pressure at Start of Main (psi)				Pressure at Start at Main (psi)			
		26	30	40	50	26	30	40	50	26	30	40	50
1"	50		1	2	4								
	100			1	2		NONE						
	150				1								
1-1/2	100	1	3	10	15								
	200		1	5	8		NONE						
	300		1	3	5								
2"	100	2	10	15	15								
	250	1	4	10	10		NONE						
	500		2	6	6								
3"	200	7	15				2570 Feet of ≦3" serving 12 customers.						
	500	3	10										
	1,000	1	5										

NOTES:
a) Table is based on dead end pipelines; number of customers may be doubled for 2" and 3" circulating pipelines only.
b) Table is based on metered customers.

4. Storage of treated water

a. Are ground level or subsurface tanks used? No

Are they sealed? ______

Are they always full? ______

Does a test program exist to test them for leaks? ______

Are vents inverted and protected from admitting insects, animals, etc.? ______

Is tank at high point of surrounding area to provide surface drainage away from tank? ______

b. Are elevated tanks used? Yes

Where are they located with respect to pump units?

- i. At pump unit? ______
- ii. At far end of area served? ✓
- iii. In middle of area served? ______

Are tanks sealed and protected from intrusion of insects, birds, rainwater? Yes

Are vents inverted and screened? Yes

c. Are open reservoirs used? No

Are they protected from intrusion by humans and other animals? ______

Is chlorine residual maintained? ______

Is treatment provided to prevent growth of algae and other plankton which are odor and taste formers? ______

Is water chlorinated at discharge and at least 0.4 mg/ℓ residual maintained not less than 30 minutes prior to reaching customer? See paragraph f, page D-5. ______

5. Capacity Rating

a. Has water system ever discontinued or curtailed service to customers due to lack of adequate distribution capacity and pressure? NO

i. Times per year (average) 0

ii. Days per time (average) —

iii. Percentage of distribution system per time (average) —

iv. Historical distribution capability

$$B_D = \left[\frac{365-(\overset{0}{\cancel{ii}})(i)}{365}\right] \times \text{iii} = 1.0$$

b. Consider ratios of 3. a. vii and 3. b above.

B. Distribution Reliability

1. Model the distribution system using Figure E-1 and detail each operation following the procedures in Appendix A. Enter A. 5. a. iv into the reliability evaluation as historical reliability for the subsystem. See pages E-15 through E-21 for demonstration system.

2. Consider pumps and standbys from A. 1 and A. 2 above.

3. Consider one and two direction supply areas in the model from A. 3. d. Use Figure E-2 for reliability.

4. Calculate the probability of pressure loss due to peak demand load using data from A. 3. f as follows:

$$P.L._D = 1-\left[\frac{8760\text{-Hrs of Pres. Loss}}{8760}\right] \times / \text{ \% of system}$$

$$= 1-\left[\frac{8760-0}{8760}\right] \times / \% = \underline{\quad 0 \quad}.$$

C. Distribution Design and Maintenance Adequacy

1. Portion of system (from A. 3. 1) having 35-year or greater life expectancy 90 %

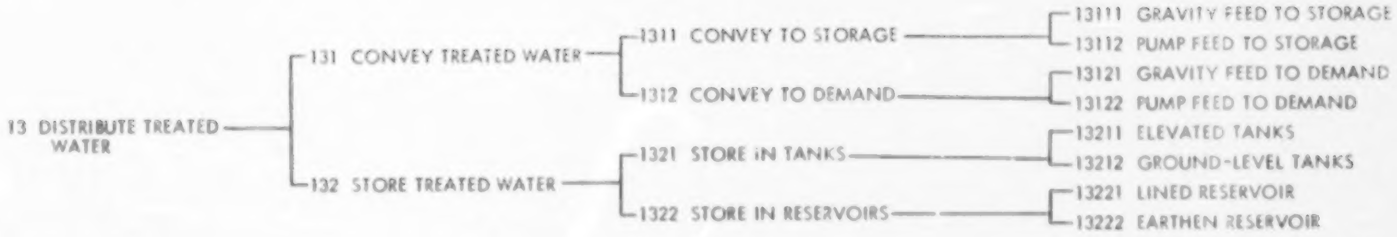

13 DISTRIBUTE TREATED WATER
131 CONVEY TREATED WATER
132 STORE TREATED WATER
1311 CONVEY TO STORAGE
1312 CONVEY TO DEMAND
1321 STORE IN TANKS
1322 STORE IN RESERVOIRS
13111 GRAVITY FEED TO STORAGE
13112 PUMP FEED TO STORAGE
13121 GRAVITY FEED TO DEMAND
13122 PUMP FEED TO DEMAND
13211 ELEVATED TANKS
13212 GROUND-LEVEL TANKS
13221 LINED RESERVOIR
13222 EARTHEN RESERVOIR

Figure E-1. Structure and Matrix for Distribution of Treated Water, Subsystem 13

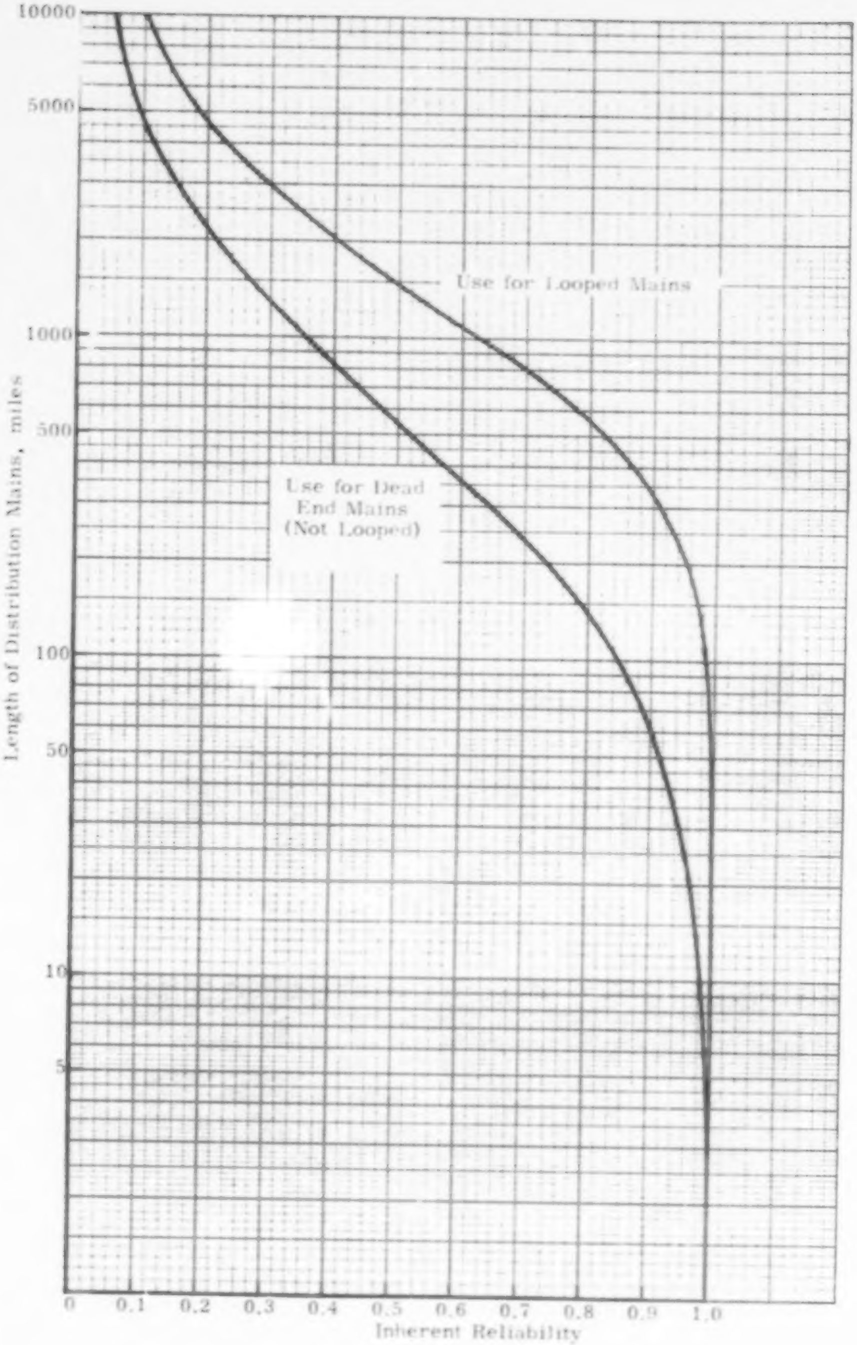


Figure E-2. Distribution Main Reliability with Respect to Installed Length

2. Number of miles of pipe with dead ends 10 miles

(from A. 3. d) Number of dead ends 16

Average number of dead ends showing contamination per year 0

Ratio of contamination to total dead ends =

0 ÷ 16 = 0 .Adequacy = 1 - Ratio = 1.0

3. Number of flow interruptions involving more than one block 6

Ratio of interruptions involving more than one block to total blocks served

6 ÷ 434 = .0138 . Adequacy = 1 - Ratio = 0.9862

4. Adequacy of mains 3 inches and smaller and number of customers. Total number of connections exceeding desirable number (from A. 3. m) divided by total number of connections.

0 ÷ ____ = 0 . Adequacy = Ratio = 1.0

5. Number of repairs utilizing proper disinfection, flushing, and testing divided by total system repairs (average per year), see A. 3. n. 15 ÷ 15 =

1.0 = repair disinfection adequacy.

6. Leak repair adequacy = number of leaks repaired per year divided by total number discovered (from A. 3. o) = 156 ÷ 156 = 1.0

7. Using distribution reliability model from B, model probability of not having a cross-connection contamination as follows:

Using reliability for distribution from Appendix A, raise the subsystem reliability (R_1 x R_2) to the power of the number of cross-connections found per year (from A. 3. q), cross-connection potential = $(.9862)^{(72)}$ = 0.3677 if the nature of the cross-connection hazard is identified, compute the probability of not exceeding the constituent limits of the drinking water standards and multiply by the cross-connection potential to obtain the probability of not contaminating the subsystem. Enter the result into the Appendix A and B analyses for the distribution subsystem.

8. Adequacy of valve maintenance program is the number of times per year (average) that interruptions of excessive areas (over one block) were required divided by total number of interruptions = 6 ÷ 156 = .0384

   Adequacy = 1 - Result = 1 - .0384 = 0.9616

9. Refer to the failure modes and effects analysis in Appendix I, Figure I-6, to determine effects of failure on system reliability. The effects should be considered when modeling the system for reliability analysis.

D. Quality Surveillance of the Distribution System

1. Calculate the probability that distributed water exceeds the constituent limits of the drinking water standards and the water quality rating using the procedures of Appendix B. See pages E-22 through E-26 for the demonstration system.

2. Using the same methods (Appendix B), calculate the following control analysis probabilities.

   a. Aluminum - probability of exceeding 0.05 mg/ℓ

   b. Chlorine residual - probability of exceeding 0.4 mg/ℓ

   c. Hardness - probability of exceeding 80 mg/ℓ

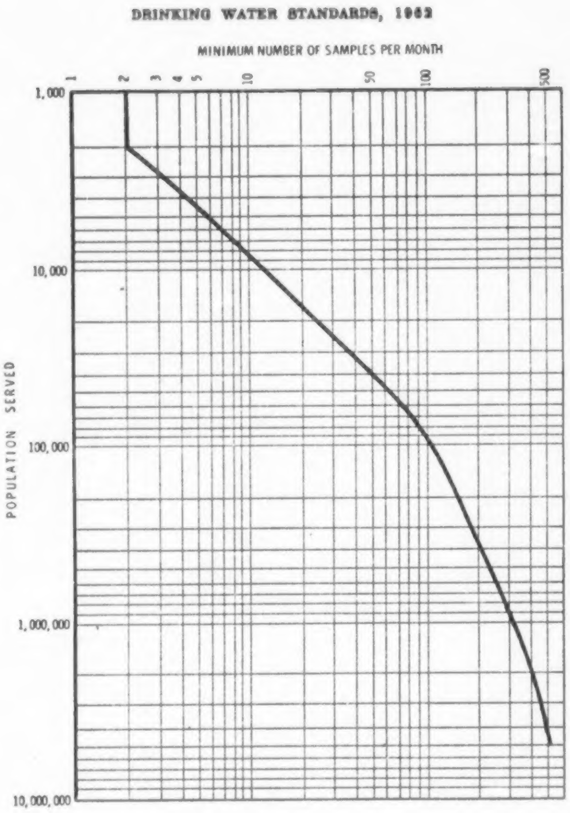
   d. pH - probability of falling outside of range from 5.6 to 9.5 (use same technique as for flouride content).

3. Does bacteriological sampling conform to the minimum required by the drinking water standards (see Figure E-4)?

Required number per month = Yes

Number taken per month = 52

52 Are taken by the water system laboratory. Other samples are taken by the State Health Department.



The minimum number of samples to be collected from the distribution system and examined each month should be in accordance with the number on the graph for the population served by the system. For the purpose of uniformity and simplicity in application, the number determined from the graph should be in accordance with the following: for a population of 25,000 and under – to the nearest 1; 25,001 to 100,000 – to the nearest 5; and over 100,000 – to the nearest 10.

In determining the number of samples examined monthly, the following samples may be included, provided all results are assembled and available for inspection and the laboratory methods and technical competence of the laboratory personnel are approved by the Reporting Agency and the Certifying Authority:

(a) Samples examined by the Reporting Agency
(b) Samples examined by local government laboratories
(c) Samples examined by the water works authority
(d) Samples examined by commercial laboratories

The laboratories in which these examinations are made and the methods used in making them shall be subject to inspection at any time by the designated representative of the Certifying Authority and the Reporting Agency. Compliance with the specified procedures and the results obtained shall be used as a basis for certification of the supply.

Daily samples collected following a bacteriologically unsatisfactory sample shall be considered as special samples and shall not be included in the total number of samples examined. Neither shall such special samples be used as a basis for prohibiting the supply, provided that: (1) when waters of unknown quality are being examined, simultaneous tests are made on multiple portions of a geometric series to determine a definitive coliform content; (2) immediate and active efforts are made to locate the cause of pollution; (3) immediate action is taken to eliminate the cause; and (4) samples taken following such remedial action are satisfactory.

Figure E-4. Sampling Rate for Bacteriological Analysis

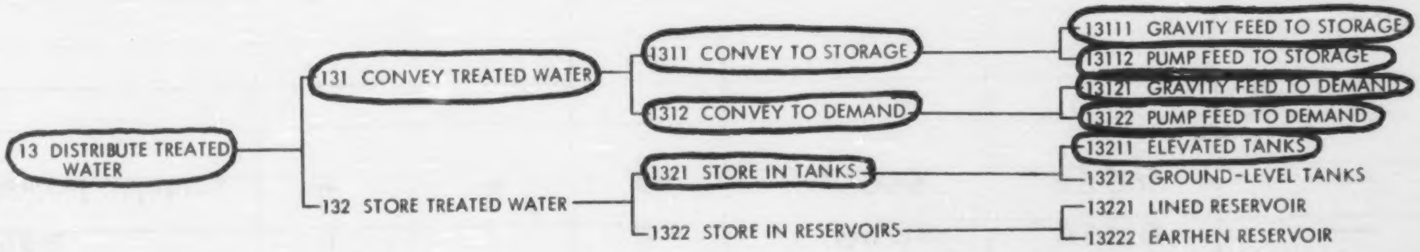

13 DISTRIBUTE TREATED WATER
131 CONVEY TREATED WATER
132 STORE TREATED WATER
1311 CONVEY TO STORAGE
1312 CONVEY TO DEMAND
1321 STORE IN TANKS
1322 STORE IN RESERVOIRS
13111 GRAVITY FEED TO STORAGE
13112 PUMP FEED TO STORAGE
13121 GRAVITY FEED TO DEMAND
13122 PUMP FEED TO DEMAND
13211 ELEVATED TANKS
13212 GROUND-LEVEL TANKS
13221 LINED RESERVOIR
13222 EARTHEN RESERVOIR

Figure E-1. Structure and Matrix for Distribution of Treated Water, Subsystem 13

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Gravity Feed to Clearwells -- Distribution

Stage Identification Number: 13111

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N R (from Fig. F-2)	R^N	Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
PIPE	1	1	0	.9989	.9989	—
Manual Valves	4	4	0	.9999	.9996	—
Series Components Reliability = Product of $R_i^N = R_1$ =					.995	
Standby Components Reliability = Product of $R_i = R_2$ =						—
Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .995 x — = .995						
Enter R in Column (5) of Table F-2.						

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Gravity Feed & Pump Feed the Demand and Storage --Dist.

Stage Identification Number: 13111, 13112, 13122, 13122

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)	
Pumps, High Lift	4	1	3	—	—	1–	Creek
Manual Valves	4	1	3	—	—	1–	
Check Valves	4	4	0	.9998	.996	—	
Pipe	1	1	0	.9989	.9989	—	
Electric Power	2	2	0	.9991	.998	—	
Recorders	5	5	0	.9988	.992	—	
Pumps, High Lift	2	1	1	–	–	1–	River
Control Valves	2	2	0	.9996	.998	—	
Manual Valves	4	2	2	–	–	1–	
Check Valves	2	2	0	.9998	.998	—	
Electric Power	1	1	0	.9991	.9991	—	
Pipe	1	1	0	.9989	.9989	—	

Series Components Reliability = Product of $R_i^N = R_1 =$

Standby Components Reliability = Product of $R_i = R_2 =$ (CONTINUED)

Unit Operation Reliability, R = Product of $R_1 \times R_2 =$ ___ x ___ = ___

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Gravity Feed & Pump Feed the Demand & Storage—Dist.

Stage Identification Number: 13111, 13112, 13122, 13122 (CONTINUED)

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Recorders	8	8	0	.9988	.986	—
Manual Valves	4	4	0	.9999	.9996	—
Pipe	1	1	0	.9989	.9989	— Mountain Source
Piping, Distribution, Looped	67 miles	—	—	—	—	.96
Piping, Distribution, Not Looped	10 miles	—	—	—	.96	—
Manual Valves	1131	1131	0	.9999	.893	—
Fire Hydrants	1173	1173	0	.9999	.889	—
Booster Pump	2	1	1	—	—	.9999
Booster Pump	2	1	1	—	—	.9999 Distribution Main System

.2

Series Components Reliability = Product of $R_i^N = R_1 =$ .735

Standby Components Reliability = Product of $R_i = R_2 =$ .959

Unit Operation Reliability, R = Product of $R_1 \times R_2 =$ .735 × .959 = .704

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Store in Elevated Tanks Distribution

Stage Identification Number: 13211

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Same as matrix (Figure F-3).					.9970	

Series Components Reliability = Product of R_i^N = R_1 = .9970

Standby Components Reliability = Product of R_i = R_2 =

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = ___ x ___ = .9970

Enter R in Column (5) of Table F-2.

TABLE A-2. SUBSYSTEM RELIABILITY

Subsystem Description: Distribute Treated Water

Stage Identification Number: 13

(1) Operation Identification Number	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Unit Operation Reliability R_i	(6) If n=N, Compute R_i^N	(7) If n + s = N, enter R_i on curve R_1 in Fig. F-1, move horizontally to right, and read from R_2 or R_3 as appropriate for number of standbys
13111	1	1	0	.995	.995	—
13112, 13113, [illegible]	1	1	0	.704	.704	—
13311	2	2	0	.9970	.991	—

Series Operations Reliability = Product of R_i^N = R_1 = .694

Standby Operations Reliability = Product of R_i = R_2 = —

Subsystem Reliability = Product of $R_1 \times R_2$ = .694 × — = .694 = R_{ss}

Subsystem Historical Water Supply Capability = [illegible] = B_{ss}

Subsystem Ability to Furnish Water = $R_{ss} \times B_{ss}$ .694 × [illegible] = .684

TABLE A-5. OPERATION RELATIVE FAILURE EFFECT

DISTRIBUTE TREATED WATER

(1) Operation Number (From Table F-2)	(2) Failure Effect Weighting Factor, F (From Table F-4)	(3) Operation Weight Factor Fraction & $1-(F_i/\sum_{i=1}^{n} F_i)$	(4) Actual Operation Reliability, R_i (From Table F-2)	(5) Highest Operation Achievable Reliability, R_h	(6) Actual Operation Failure Effect (3 x (4)	(7) Lowest Operation Failure Effect (3) x (5)	(8) Operation Rating (6) ÷ (7)
13111	63504000	.988	.995	.999	.983	.987	1.00
13112, 13121, 13122	63504000	.988	.704	.999	.695	.987	.70
13211	7056000	.998	.991	.999	.989	.997	.99
APP. E, 4.3.8.	2800	.999	1.00	1.00	.999	.999	1.00
C.2	450	.999	1.00	1.00	.999	.999	1.00
C.3	320	.999	.986	1.00	.985	.999	.99
C.4	320	.999	1.00	1.00	.999	.999	1.00
C.5	10	.999	1.00	1.00	.999	.999	1.00
C.6	320	.999	1.00	1.00	.999	.999	1.00
C.7	40500	.999	.367	1.00	.367	.999	.37
C.8	160	.999	.961	1.00	.960	.999	.96
			$\frac{10.01}{11}$ = .91				10.01

Summation, $\sum_{i=1}^{n} F_i$ = 592484163 FOR ENTIRE SYSTEM

Distribution ~~Sub~~ System Failure Effect Rating $\frac{\sum_{i=1}^{n}[(6) \div (7)]_i}{n}$ = .91

(sheet 1 of 2)

WATER CONSTITUENT DATA

Use Certified Laboratory Sources Only

Data Sources: Treatment Laboratory ✓ County Health Department ____ State Health Department ____

Water Supply System: Name Demonstration System

Location ____

Data for: Raw Water ____ Treated Water ____ Distributed Water ✓

Constituent	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Scale Values				Probability of Exceeding DWS:	
	Recommended Limit, X_1	Mandatory Limit, X_2	$\bar{X}$ Mean	s Deviation	N, No. of Tests	95% Confidence Limits $\bar{X}' = \bar{X} + \frac{2s}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2s}{\sqrt{n}}$	$\frac{X_1 - \bar{X}'}{s}$	$\frac{X_2 - \bar{X}'}{s}$	$\frac{X_L - \bar{X}''}{s}$	$\frac{X_1 - \bar{X}'}{s}$	Recommended Limit	Mandatory Limit
Nonremovables:										For Fluoride Only	For Fluoride Only		
Alkyl Benzene Sulfonate, ABS	0.5 mg/l												
Arsenic, As	0.01	0.05 mg/l											
Barium, Ba		1.0											
Cadmium, Cd		0.01											
Chromium, Hexavalent, Cr^{+6}		0.05											
Chloride, Cl	250.												
Copper, Cu	1.0		.74	.24	10	.89		.457				.32	
Carbon Chloroform Extract, CCE	0.2												
Cyanide, CN	0.01	0.2											
Lead, pb		0.05											
Nitrate, NO_3	45.												
Selenium, Se		0.01											
Silver, Ag		0.05											
Sulfate, SO_4	250.												
Zinc, Zn	5.												
Radium -226		3μμc/l											
Strontium-90		10μμc/l											
Removables:													
Coliform	(a) X_1 or X_2: 10% + /month using 10 ml portions		[illegible]	.2494	623	.0039		10.25				0*	
	(b) ≥3 + (using 10 ml portions) in 2 consecutive samples in ≥1 sample when <20 samples/month, or >5% when ≥20 samples/month												
	(c) 1/100 ml avg/mo.; or ≥3/50 ml, >4/100 ml, 7/200 ml, 13/500 ml												
Color	15 units												

* 2+ in 623 tests : $\frac{2}{623} = .0032$

Figure B-3. Calculations for Probability of Exceeding the Drinking Water Standards

(sheet 2 of 2)

Distributed Water -- SYSTEM CAB.

	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Score Values				Probability of Exceeding DWS:	
Constituent	Recommended Limit, X_1	Mandatory Limit, X_2	$\bar{X}$ Mean	σ Deviation	N, No. of Tests	$\bar{X}' = \bar{X} + \frac{2\sigma}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\sigma}{\sqrt{n}}$	$\frac{X_1 - \bar{X}'}{\sigma}$	$\frac{X_2 - \bar{X}'}{\sigma}$	$\frac{X_L - \bar{X}''}{\sigma}$	$\frac{X_U - \bar{X}'}{\sigma}$	Recommended Limit	Mandatory Limit
Removables (Cont'd)													
Fluoride, F	Avg. Temp. F(LWR) X_L	F(Upper) X_U											
	50.0-53.7°F 0.9	1.7	.96	.09	34	.99	.93			.33	7.9	0 ** ~~.64~~	
	53.8-58.3°F 0.8	1.5											
	58.4-63.8°F 0.8	1.3											
	63.9-70.6°F 0.7	1.2											
	70.7-79.2°F 0.7	1.0											
	79.3-90.5°F 0.6	0.8											
Iron, Fe (COLD [illegible])	[illegible]/l		.34	.292	18	.45		-.51				.71	
Manganese, Mn	0.5 mg/l												
Odor, Threshold Number	3												
Phenols	0.001 mg/l												
Tastes	Not objectionable												
Total Dissolved Solids, TDS	500. mg/l												
Turbidity	5 units												

[1] In 2 consecutive samples, or in >1 sample when <20 samples/month, or in >5% of samples when >20 samples/month.

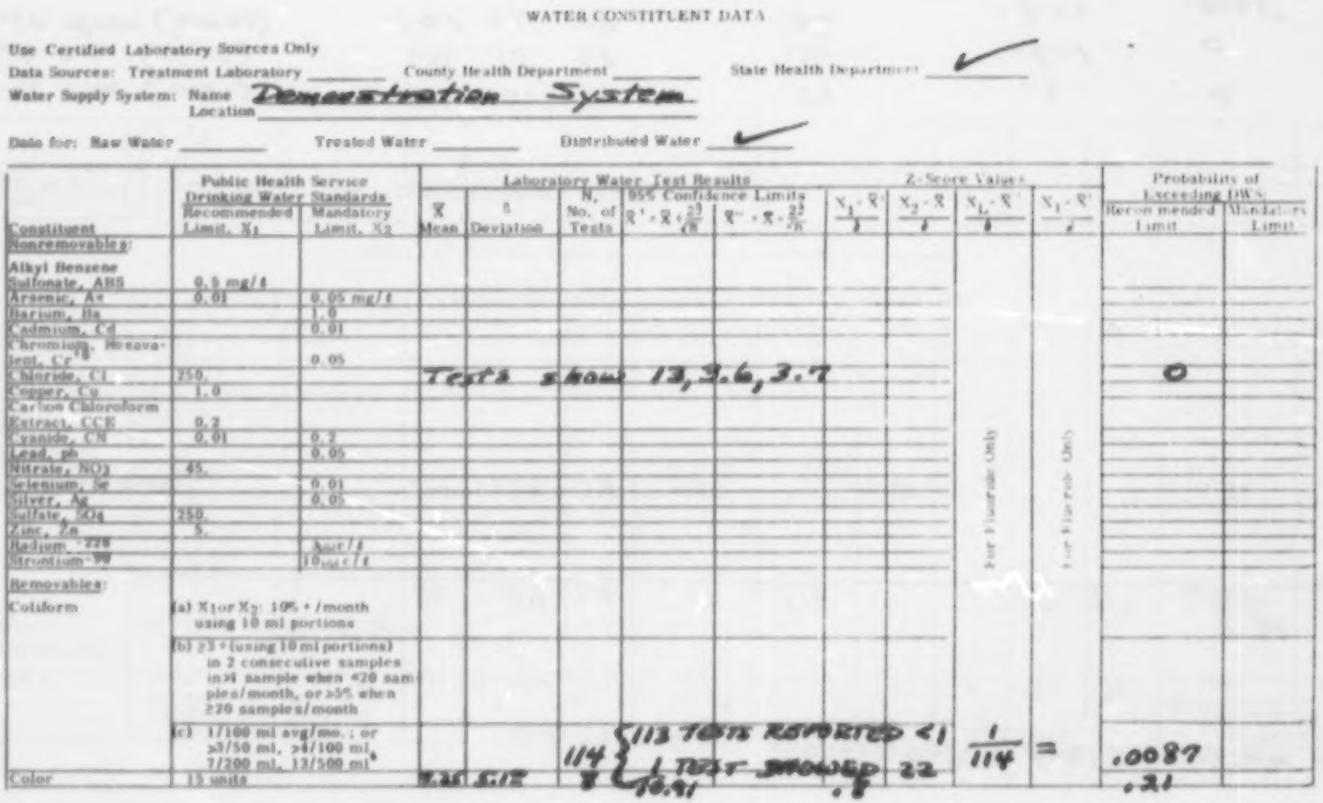
Control Characteristics Measurement (Treated and Distributed Water)

Aluminum	0.05 mg/l												
Chlorine Residual	0.4 mg/l *	AS	COMBINED		CHLORINE								
Hardness	80 mg/l												
Ph	X_L X_U 5.6 9.5												
*Point One (west)			1.17	.08	28		.87			-9		0	
Point two (south)			1.01	.115	28		.95			-4.28		0	
Point three (west)			1.05	.23	28		.96			-2.43		.0065	

** $P(F \geqq 1.7) = 0$, $P(F \leqq 0.9) = .64$

Figure B-3 (Continued)

(sheet 1 of 2)



WATER CONSTITUENT DATA

Use Certified Laboratory Sources Only

Data Sources: Treatment Laboratory ______ County Health Department ______ State Health Department ✓

Water Supply System: Name Demonstration System

Location ______

Data for: Raw Water ______ Treated Water ______ Distributed Water ✓

Constituent	Public Health Service Drinking Water Standards		Laboratory Water Test Results					Z-Score Values				Probability of Exceeding DWS	
	Recommended Limit, X_1	Mandatory Limit, X_2	$\bar{X}$ Mean	s Deviation	N, No. of Tests	95% Confidence Limits $\bar{X}' = \bar{X} + \frac{2s}{\sqrt{N}}$	$\bar{X}'' = \bar{X} - \frac{2s}{\sqrt{N}}$	$\frac{X_1 - \bar{X}'}{s}$	$\frac{X_2 - \bar{X}}{s}$	$\frac{X_L - \bar{X}'}{s}$	$\frac{X_1 - \bar{X}'}{s}$	Recommended Limit	Mandatory Limit
Nonremovables:													
Alkyl Benzene Sulfonate, ABS	0.5 mg/ℓ												
Arsenic, As	0.01	0.05 mg/ℓ											
Barium, Ba		1.0											
Cadmium, Cd		0.01											
Chromium, Hexavalent, Cr^{+6}		0.05											
Chloride, Cl	250.		Tests show 13, 3.6, 3.7							For Fluoride Only	For Fluoride Only	0	
Copper, Cu	1.0												
Carbon Chloroform Extract, CCE	0.2												
Cyanide, CN	0.01	0.2											
Lead, pb		0.05											
Nitrate, NO_3	45.												
Selenium, Se		0.01											
Silver, Ag		0.05											
Sulfate, SO_4	250.												
Zinc, Zn	5.												
Radium-226		3μμc/ℓ											
Strontium-90		10μμc/ℓ											
Removables:													
Coliform	(a) X_1 or X_2: 10% + /month using 10 ml portions												
	(b) ≥3 + (using 10 ml portions) in 2 consecutive samples in ≥1 sample when <20 samples/month, or ≥5% when ≥20 samples/month												
	(c) 1/100 ml avg/mo.; or ≥3/50 ml, ≥4/100 ml, 7/200 ml, 13/500 ml				114	113 TESTS REPORTED <1 1 TEST SHOWED 22				$\frac{1}{114}$	=	.0087	
Color	15 units		7.36	5.17	8	10.91		.8				.21	

Figure B-3. Calculations for Probability of Exceeding the Drinking Water Standards

(sheet 2 of 2)

Distributed Water -- State Lab.

Constituent	Public Health Service Drinking Water Standards: Recommended Limit, X_1	Public Health Service Drinking Water Standards: Mandatory Limit, X_2	Laboratory Water Test Results: $\bar{X}$ Mean	σ Deviation	N, No. of Tests	$\bar{X}' = \bar{X} + \frac{2\sigma}{\sqrt{n}}$	$\bar{X}'' = \bar{X} - \frac{2\sigma}{\sqrt{n}}$	Z-Score Values: $\frac{X_1 - \bar{X}'}{\sigma}$	$\frac{X_2 - \bar{X}'}{\sigma}$	$\frac{X_L - \bar{X}''}{\sigma}$	$\frac{X_U - \bar{X}'}{\sigma}$	Probability of Exceeding DWS: Recommended Limit	Mandatory Limit
Removables (Cont'd)													
Fluoride, F	Avg. Temp. F(LWR) X_L	F (Upper) X_U											
	50.0-53.7°F 0.9	1.7	.97	.44	6	1.33	.61			.66	.84	.22 .99**	
	53.8-58.3°F 0.8	1.5											
	58.4-63.8°F 0.8	1.3											
	63.9-70.6°F 0.7	1.2											
	70.7-79.2°F 0.7	1.0											
	79.3-90.5°F 0.6	0.8											
Iron, Fe	0.3 mg/ℓ												
Manganese, Mn	0.5 mg/ℓ												
Odor, Threshold Number	3												
Phenols	0.001 mg/ℓ												
Tastes	Not objectionable												
Total Dissolved Solids, TDS	500. mg/ℓ		124	60.4	8	166		5.57				0	
Turbidity	5 units		2.8	1.03	8	3.5		1.46				.07	

*In 2 consecutive samples, or in >1 sample when <20 samples/month, or in >5% of samples when >20 samples/month.

Control Characteristics Measurement (Treated and Distributed Water)

Aluminum	0.05 mg/ℓ												
Chlorine Residual*	0.4 mg/ℓ		.366	.235	100	.319				.3466		.62	
Hardness	80 mg/ℓ		53.8	48.8	8	82.3			-.16			.38	
Ph ***	X_L 5.6 X_U 9.5		7.42	.328	100	7.5	6.6			-3.05	6.09	.0016	

*Total combined chlorine.

** $P(F \leq .9) = .77$, $P(F \geq 1.7) = .22$ This comes from only 6 tests.

*** Lead service connections are prevalent in the system; however, pH range appears satisfactory to prevent dissolution of lead.

Figure B-3 (Continued)

DISTRIBUTED WATER

(1) Constituent	(2) Weight Factor	(3) 1 - P(≥ DWS) P(≥ DWS) from Fig. G-3	(4) (2) x (3)	(5) $(2) \times (3) \div \frac{\sum_{i=1}^{n} \|(2) \times (3)\|_i}{\sum_{i=1}^{n} (2)_i}$
Bacteria:				
Coliform	10	0.0032	0.032	0.20
Physical:				
Turbidity	9	0.07	0.63	3,94
Color	9	0.21	1.89	11,81
Threshold Odor	9			
Taste	9			
Chemical, Recommended:				
ABS	9			
As	9			
Cl	9	0.00	0.00	0.00
Cu	9	0.33	2.97	18.56
CCE	9			
CN	9			
Fe	9	0.71	6.39	39.94
Mn	9			
NO_3	9			
Phenols	9			
SO_4	9			
TDS	9	0.00	0.00	0.00
Zn	9			
Chemical, Mandatory:				
As	10			
Ba	10			
Cd	10			
Cr^{+6}	10			
CN	10			
F	10	0.00	0.00	0.00
Pb	10			
Se	10			
Ag	10			
Radioactivity:				
Ra^{226}	10			
Sr^{90}	10			
	74		$\sum_{i=1}^{n} \|(2) \times (3)\|_i =$ 11.912	
Distributed Water Rating =		1 -	$\frac{\sum_{i=1}^{n} \|(2) \times (3)\|_i}{\sum_{i=1}^{n} (2)_i} =$ .84	

Figure B-6. Rating of System Ability to Meet Constituent Limits of Public Health Service Drinking Water Standards of 1962

APPENDIX F

SURVEY OF WATER QUALITY SURVEILLANCE

A. Sampling and Testing Covered in Appendices B, C, D, and E.

B. Laboratory – Subjectively rate on 0.0 to 1.0 scale considering the following:

1. Is laboratory certified? Yes
2. Are services procured from a certified laboratory? No
3. Are tests performed in accordance with Standard Methods for the Examination of Water and Wastewater? Yes
4. Is laboratory orderly and clean? Yes
5. Is there any significant difference between water laboratory test results and health department or other test results? Yes*

   *Chlorine Residual
6. Are samples from the distribution system taken at random from the entire system or from predetermined locations? ______
7. Are laboratory chemists or technicians properly trained and experienced in the performance of water analysis? Yes
8. The structure of tests is shown in Figure F-1.
9. Refer to the failure modes and effects analysis, Appendix I, Figure I-8, for guidelines in failure modes and effects.

RATING = 0.85

C. Control of treatment is structured in Figure G-1; however, the constituent tests for control are given in Subsection D of Appendix E.

D. See pages F-3, F-4, and F-5 for the demonstration system.

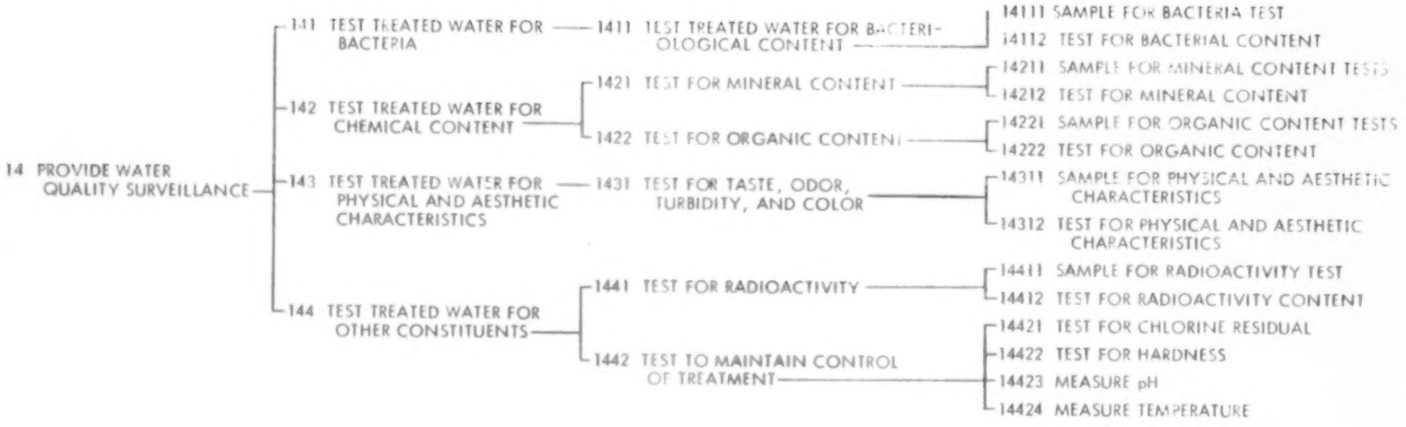
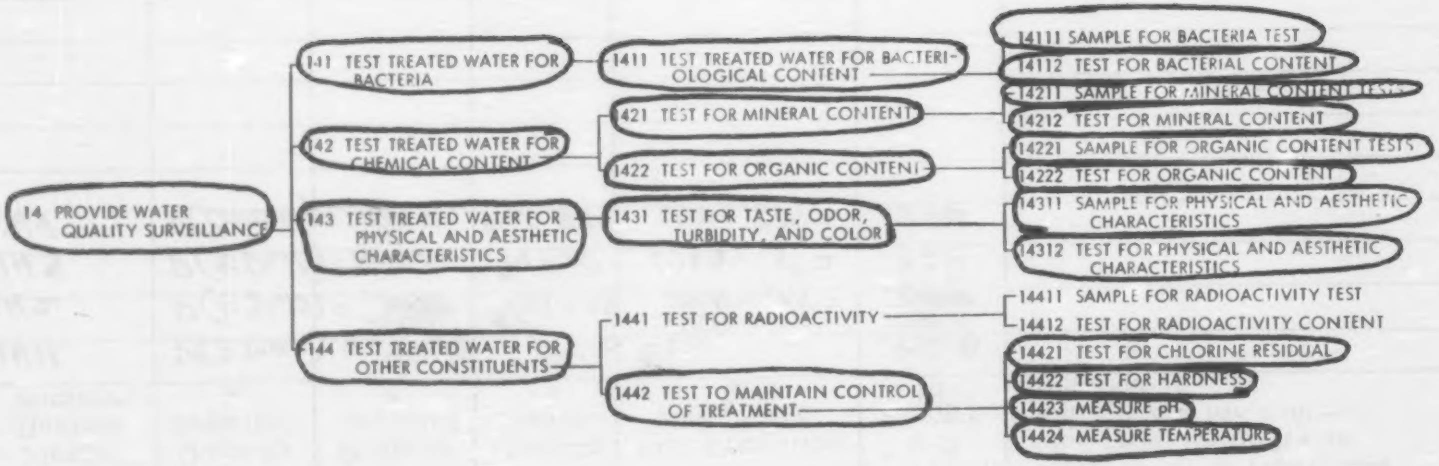

14 PROVIDE WATER QUALITY SURVEILLANCE
141 TEST TREATED WATER FOR BACTERIA
1411 TEST TREATED WATER FOR BACTERIOLOGICAL CONTENT
14111 SAMPLE FOR BACTERIA TEST
14112 TEST FOR BACTERIAL CONTENT
142 TEST TREATED WATER FOR CHEMICAL CONTENT
1421 TEST FOR MINERAL CONTENT
14211 SAMPLE FOR MINERAL CONTENT TESTS
14212 TEST FOR MINERAL CONTENT
1422 TEST FOR ORGANIC CONTENT
14221 SAMPLE FOR ORGANIC CONTENT TESTS
14222 TEST FOR ORGANIC CONTENT
143 TEST TREATED WATER FOR PHYSICAL AND AESTHETIC CHARACTERISTICS
1431 TEST FOR TASTE, ODOR, TURBIDITY, AND COLOR
14311 SAMPLE FOR PHYSICAL AND AESTHETIC CHARACTERISTICS
14312 TEST FOR PHYSICAL AND AESTHETIC CHARACTERISTICS
144 TEST TREATED WATER FOR OTHER CONSTITUENTS
1441 TEST FOR RADIOACTIVITY
14411 SAMPLE FOR RADIOACTIVITY TEST
14412 TEST FOR RADIOACTIVITY CONTENT
1442 TEST TO MAINTAIN CONTROL OF TREATMENT
14421 TEST FOR CHLORINE RESIDUAL
14422 TEST FOR HARDNESS
14423 MEASURE pH
14424 MEASURE TEMPERATURE

Figure F-1. Structure and Matrix of the Water Quality Surveillance Subsystem


14 PROVIDE WATER QUALITY SURVEILLANCE
141 TEST TREATED WATER FOR BACTERIA
142 TEST TREATED WATER FOR CHEMICAL CONTENT
143 TEST TREATED WATER FOR PHYSICAL AND AESTHETIC CHARACTERISTICS
144 TEST TREATED WATER FOR OTHER CONSTITUENTS
1411 TEST TREATED WATER FOR BACTERIOLOGICAL CONTENT
421 TEST FOR MINERAL CONTENT
1422 TEST FOR ORGANIC CONTENT
1431 TEST FOR TASTE, ODOR, TURBIDITY, AND COLOR
1441 TEST FOR RADIOACTIVITY
1442 TEST TO MAINTAIN CONTROL OF TREATMENT
14111 SAMPLE FOR BACTERIA TEST
14112 TEST FOR BACTERIAL CONTENT
14211 SAMPLE FOR MINERAL CONTENT TESTS
14212 TEST FOR MINERAL CONTENT
14221 SAMPLE FOR ORGANIC CONTENT TESTS
14222 TEST FOR ORGANIC CONTENT
14311 SAMPLE FOR PHYSICAL AND AESTHETIC CHARACTERISTICS
14312 TEST FOR PHYSICAL AND AESTHETIC CHARACTERISTICS
14411 SAMPLE FOR RADIOACTIVITY TEST
14412 TEST FOR RADIOACTIVITY CONTENT
14421 TEST FOR CHLORINE RESIDUAL
14422 TEST FOR HARDNESS
14423 MEASURE pH
14424 MEASURE TEMPERATURE

12 TESTS PERFORMED OUT OF 30 REQUIRED
(26 U.S. PUBLIC HEALTH STANDARDS TESTS
PLUS 4 CONTROL TESTS)

Figure F-1. Structure and Matrix of the Water Quality Surveillance Subsystem

TABLE A-2. SUBSYSTEM RELIABILITY

Subsystem Description: Water Quality Surveillance

Stage Identification Number: 14

(1) Operation Identification Number	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Unit Operation Reliability R_i	(6) If n=N, Compute R_i^N	(7) If n + s = N, enter R_i on curve R_1 in Fig. F-1, move horizontally to right, and read from R_2 or R_3 as appropriate for number of standbys
1411	P(≤DWS) =	.9968	52/30	≥ 1.0	.9968	
142	P(≤DWS) =	.806 [redacted]	5/21 = .25	.806 [redacted] x .25 =	.202 [redacted]	
143	P(≤DWS) =	.733	3/4 = .5	.733 x .5 =	.366	
144	P(CONTROL) =	.288	5/6 = .834	.288 x .834 =	.240	

Series Operations Reliability = Product of R_i^N = R_1 = .0177 [redacted]

Standby Operations Reliability = Product of R_i = R_2 = —

Subsystem Reliability = Product of $R_1 \times R_2$ = ___ x ___ = .0177 = R_{ss}

Subsystem Historical Water Supply Capability = ____ = B_{ss}

Subsystem Ability to Furnish Water = $R_{ss} \times B_{ss}$ ____ x ____ = .0177.

TABLE A-5. OPERATION RELATIVE FAILURE EFFECT

WATER QUALITY SURVEILLANCE

(1) Operation Number (From Table F-2)	(2) Failure Effect Weighting Factor, F (From Table F-4)	(3) Operation Weight Factor Fraction $F_i / \sum_{i=1}^{n} F_i$	(4) Actual Operation Reliability, R_i (From Table F-2)	(5) Highest Operation Achievable Reliability, R_h	(6) Actual Operation Failure Effect (3) x (4)	(7) Lowest Operation Failure Effect (3) x (5)	(8) Operation Rating (6) ÷ (7)
1411	2450	.999	.9968	1.00	.995	.999	.99
142	22050	.999	.202	1.00	.202	.999	.202
143	2205	.999	.366	1.00	.366	.999	.37
144	63504000	.988	.240	1.00	.237	.988	.24
APR F, PARA. B	63504000	.988	.85	1.00	.840	.988	.85
							2.652

$$\frac{2.652}{5} = 0.53$$

Summation, $\sum_{i=1}^{n} F_i$ = 5726180153 FOR ENTIRE SYSTEM	Water Quality Surveillance Sub-System Failure Effect Rating $\frac{\sum_{i=1}^{n} [(8) \div (7)]_i}{n}$ = .53

APPENDIX G

SURVEY OF SYSTEM SERVICES

The structure of system services is shown in Figure G-1. Failure modes and effects are given in Appendix I, Figure I-10 for consideration in modeling and in rating the subsystem. Model the system and compute reliability and failure effects using methods of Appendix A. See pages G-7 through G-14 for the demonstration system.

A. Utilities

1. Two independent power supplies with switch gear for each should be furnished where electrical power is required such as for intakes, treatment facility, all pump stations, and controls. Only one provided.

2. Model the power supply and determine reliability and failure effects using Appendix A.

3. A special note is that auxiliary power supplies should be capable of being placed on-line before water storage is depleted or risk of contamination increases.

b. Sanitary and Habitability Items

1. Sanitary facilities such as toilets, drains, and other sanitary sources of contamination should be so installed to prevent any possible contamination of treated water. If such facilities are so located that contamination may be possible, treat as common walls, and compute reliability as follows:

   a. Determine number of toilets, drains, and other sanitary sources of contamination 0

   b. Enter quantity into Figure D-3 and read reliability from abscissa. Reliability should be entered into calculations in Appendix A.

2. Habitability items such as heat, air conditioning, ventilation, safety, and emergency equipment should

function properly. Safety and emergency equipment should be properly located for easy access by personnel. Enter human engineering items into the reliability analysis of Appendix A. Check safety and emergency equipment for proper locations.

a. Breathing apparatus, gloves, goggles within easy reach of chlorine equipment and storage.

b. Fire fighting equipment should be located near hypochlorite and sodium chlorite storage and feed equipment. Sodium chlorite burns and is explosive.

c. Eye flushing fixtures should be located near chemical equipment.

Human engineering should be evident in plant design, layout, and equipment installation. Inspection points include cleanliness, location of controls within easy reach, room to move about, standard controls, safety devices, alarms, fail-safe devices, and in general an environment that fosters effective procedures, work patterns, and personnel safety and that minimizes discomfort, distractions, and other factors which degrade human performance.

Subjectively rate safety equipment location and suitability on a 0.0 to 1.0 scale with 0.25 as poor, 0.50 below average, [✓ 0.75] average, and 1.0 excellent. Enter this rating as a series reliability item in the services analysis in Appendix A.

C. Preventive Maintenance Program

1. Schedule – A schedule for assigning and recording the performance of preventive maintenance should be maintained. The schedule should describe tasks to be accomplished, intervals between accomplishment, and assigned personnel.

Personal Log

2. Labor – Maintenance should be performed by skilled personnel having knowledge, experience, and training in the proper methods of performing water system maintenance including disinfection practices, operation of equipment in the water in the water system, and particular skills as required for maintaining mechanical and electrical equipment.
3 with 20 years experience each. 3 crews, one to each experienced person.

3. Instructions – Personnel should have available, easy to read step by step procedures for performing maintenance. The instructions should be in a form suitable for use on the job. These instructions should state required personnel skill levels for the detailed maintenance task. None

4. Subjectively rate preventive maintenance on the basis of:

   a. Training and experience of personnel in water system maintenance and principles. Schooled by Chesapeake Section of AWWA.

   b. Adequacy of schedules and instructions.

   Rate on basis of 0.0 to 1.0 scale and enter as a series reliability into the reliability analysis of services in Appendix F. .85

D. Corrective Maintenance – Subjectively evaluate the same as C.2, 3, and 4 above. Enter as a series item in reliability analysis.

E. Operate the Equipment

1. Controls – Model the system using Figure E-1 and enter reliabilities in accordance with Appendix F.

2. Monitoring Equipment and Instrumentation – Model using Figure E-1 and enter reliability in accordance with Appendix F.

3. Alarm System – An annunciator and alarm system should provide indicators of operating equipment and alarms for chlorination, chemical feed, capacity, main pressure,

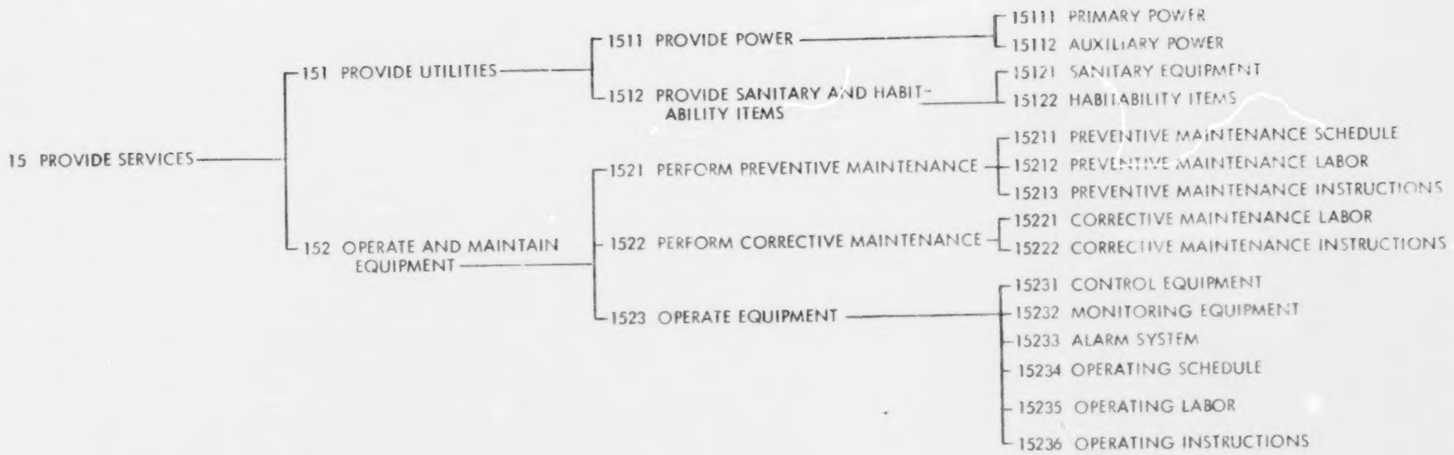

15 PROVIDE SERVICES
151 PROVIDE UTILITIES
152 OPERATE AND MAINTAIN EQUIPMENT
1511 PROVIDE POWER
1512 PROVIDE SANITARY AND HABITABILITY ITEMS
1521 PERFORM PREVENTIVE MAINTENANCE
1522 PERFORM CORRECTIVE MAINTENANCE
1523 OPERATE EQUIPMENT
15111 PRIMARY POWER
15112 AUXILIARY POWER
15121 SANITARY EQUIPMENT
15122 HABITABILITY ITEMS
15211 PREVENTIVE MAINTENANCE SCHEDULE
15212 PREVENTIVE MAINTENANCE LABOR
15213 PREVENTIVE MAINTENANCE INSTRUCTIONS
15221 CORRECTIVE MAINTENANCE LABOR
15222 CORRECTIVE MAINTENANCE INSTRUCTIONS
15231 CONTROL EQUIPMENT
15232 MONITORING EQUIPMENT
15233 ALARM SYSTEM
15234 OPERATING SCHEDULE
15235 OPERATING LABOR
15236 OPERATING INSTRUCTIONS

Figure G-1. Structure and Matrix of Services Subsystem power, reservoir levels, fire. Enter reliability using Figure E-1 in accordance with Appendix F.

4. Operating Schedule – This schedule provides a record of equipment operation, rotation, and a sequence for system loadings such as equipment required to operate at minimum load, normal load, full capacity, maximum load. Subjectively rate on 0.0 to 1.0 scale and enter as a reliability in accordance with Appendix F.

5. Labor – Subjectively rate on 0.0 to 1.0 scale and enter reliability in accordance with Appendix F. Consider the following:

   a. Are operators trained in physical, chemical, and bacteriological properties of water treatment? 10 of 15 have voluntary certification. Informally

   b. Are operators certified by state? 10 Are
5 Are Not

   c. Are operators experienced in water system operation? Yes

6. Instructions – Subjectively rate on 0.0 to 1.0 scale and enter as reliability in accordance with Appendix F. Consider the following:

   a. Are easy to follow equipment operating principles and instructions posted at operating stations and equipment? No

   b. Are system operating instructions available to chief operator at his duty station? No

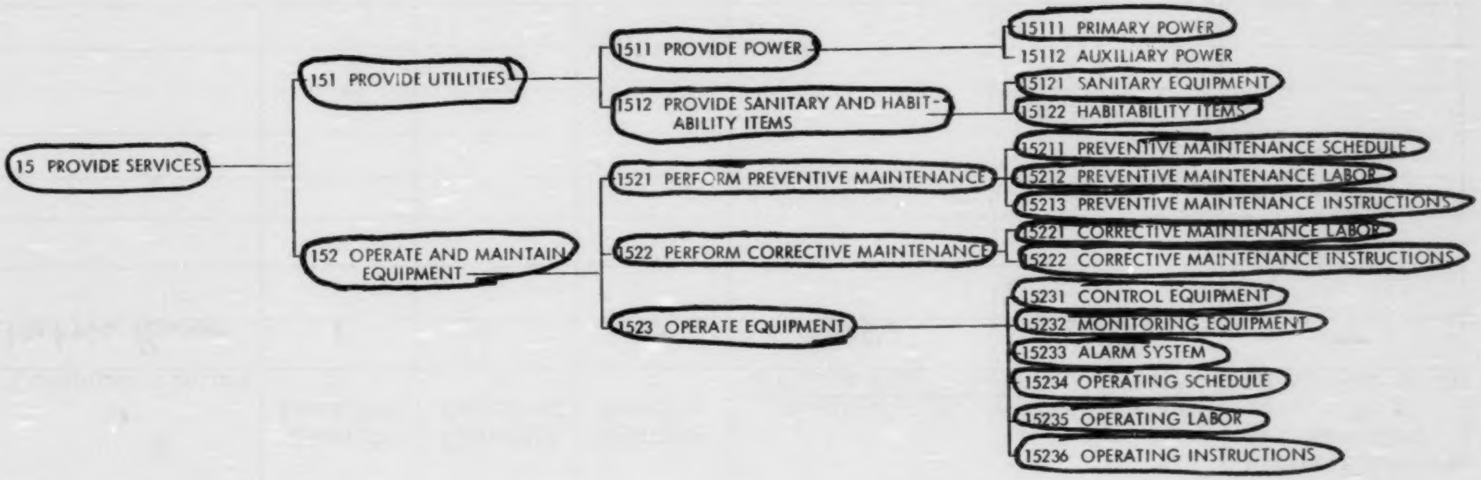

15 PROVIDE SERVICES
151 PROVIDE UTILITIES
152 OPERATE AND MAINTAIN EQUIPMENT
1511 PROVIDE POWER
1512 PROVIDE SANITARY AND HABIT-ABILITY ITEMS
1521 PERFORM PREVENTIVE MAINTENANCE
1522 PERFORM CORRECTIVE MAINTENANCE
1523 OPERATE EQUIPMENT
15111 PRIMARY POWER
15112 AUXILIARY POWER
15121 SANITARY EQUIPMENT
15122 HABITABILITY ITEMS
15211 PREVENTIVE MAINTENANCE SCHEDULE
15212 PREVENTIVE MAINTENANCE LABOR
15213 PREVENTIVE MAINTENANCE INSTRUCTIONS
15221 CORRECTIVE MAINTENANCE LABOR
15222 CORRECTIVE MAINTENANCE INSTRUCTIONS
15231 CONTROL EQUIPMENT
15232 MONITORING EQUIPMENT
15233 ALARM SYSTEM
15234 OPERATING SCHEDULE
15235 OPERATING LABOR
15236 OPERATING INSTRUCTIONS

Figure G-1. Structure and Matrix of Services Subsystem

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TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Primary Power

Stage Identification Number: 15111

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Electric Power	1	1	0	.9991	.9991	—
Series Components Reliability = Product of R_i^N = R_1 =					.9991	—
Standby Components Reliability = Product of R_i = R_2 =						
Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .9991 x — = .9991						
Enter R in Column (5) of Table F-2.						

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Habitability Items

Stage Identification Number: 15122

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Heating Equip.	1	1	0	.9903	.9903	—

Series Components Reliability = Product of $R_i^N = R_1 =$ .9903 —

Standby Components Reliability = Product of $R_i = R_2 =$

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .9903 x — = .9903

Enter R in Column (5) of Table F-2.

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Control Equipment

Stage Identification Number: 15231

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Component Name	Quantity Installed N	Quantity Required n	Quantity Standby S	Reliability, R, No Standbys, n=N		Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
				R (from Fig. F-2)	R^N	
Control Air Sys.	1	1	0	.9988	.9988	–

Series Components Reliability = Product of R_i^N = R_1 = .9988 —

Standby Components Reliability = Product of R_i = R_2 =

Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .9988 x – = .9988

Enter R in Column (5) of Table F-2.

TABLE A-1.UNIT OPERATION RELIABILITY

Operation Description: Monitoring Equipment

Stage Identification Number: 15232

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Control Monitors	1	1	0	.9988	.9988	—
Recorders	4	4	0	.9988	.961	—
Dial Indicators	4	4	0	.9999	.9996	—
Series Components Reliability = Product of $R_i^N = R_1 =$					.959	—
Standby Components Reliability = Product of $R_i = R_2 =$						
Unit Operation Reliability, R = Product of $R_1 \times R_2$ = .959 x — = .959						
Enter R in Column (5) of Table F-2.						

TABLE A-1. UNIT OPERATION RELIABILITY

Operation Description: Alarm System

Stage Identification Number: 15233

(1) Component Name	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Reliability, R, No Standbys, n=N R (from Fig. F-2)	(6) R^N	(7) Reliability, R, where standbys are installed: n + s = N; R (from Fig. F-2)
Annunciator Sys.	1	1	0	.9996	.9996	—

Series Components Reliability = Product of $R_i^N = R_1 =$ .9996 —

Standby Components Reliability = Product of $R_i = R_2 =$

Unit Operation Reliability, R = Product of $R_1 \times R_2 =$ .9996 x — = .9996

Enter R in Column (5) of Table F-2.

TABLE A-2. SUBSYSTEM RELIABILITY

Subsystem Description: System Services

Stage Identification Number: 15

(1) Operation Identification Number	(2) Quantity Installed N	(3) Quantity Required n	(4) Quantity Standby S	(5) Unit Operation Reliability Ri	(6) If n=N, Compute R_i^N	(7) If n + s = N, enter Ri on curve R_1 in Fig. F-1, move horizontally to right, and read from R_2 or R_3 as appropriate for number of standbys
15111	1	1	0		.9991*	
15121					1.0 **	
15122	2	2	0	.9903	.981*	
Safety Equipment					.75 **	
15211→15213					.85**	
15221→15222					.85**	
15231→15233	1	1	0	.939	.939*	
15234→15236					.50**	
	* Product of equipment reliabilities =					.920
	** Product of subjective evaluations =					.362

Series Operations Reliability = Product of R_i^N = R_1 = .920 x .362 = .333

Standby Operations Reliability = Product of R_i = R_2 =

Subsystem Reliability = Product of R_1 x R_2 = ___ x ___ = ___ = R_{SS}

Subsystem Historical Water Supply Capability = ___ = B_{SS}

Subsystem Ability to Furnish Water = R_{SS} x B_{SS} ___ x ___ = .333

TABLE A-5. OPERATION RELATIVE FAILURE EFFECT

PROVIDE SERVICES

(1) Operation Number (From Table F-2)	(2) Failure Effect Weighting Factor, F (From Table F-4)	(3) Operation Weight Factor Fraction $1-(F_i \div \sum_{i=1}^{n} F_i)$	(4) Actual Operation Reliability, R_i (From Table F-2)	(5) Highest Operation Achievable Reliability, R_u	(6) Actual Operation Failure Effect (3) x (4)	(7) Lowest Operation Failure Effect (3) x (5)	(8) Operation Rating (6) ÷ (7)
15111	6272000	.998	.9991	.9999	.998	.998	1.00
15121	2800	.999	1.00	1.00	.999	.999	1.00
15122	280	.999	.981	.999	.980	.998	.98
1521	508032000	.911	.85	1.00	.774	.911	.85
1522	2540160000	.556	.85	1.00	.472	.556	.85
15231	6272000	.998	.9988	.9999	.997	.998	1.00
15232	78400	.999	.959	.999	.958	.998	.96
15233	627200	.999	.9996	.999	.998	.998	1.00
15234	62720	.999	.78	1.00	.770	.999	.77
15235	508032000	.911	.85	1.00	.774	.911	.85
15236	508032000	.911	.76	1.00	.692	.911	.76
APP. G. PARA. B.2	78400	.999	.75	1.00	.740	.999	.74
							10.76
			$\frac{10.76}{12}$	= .90			

Summation, $\sum_{i=1}^{n} F_i$ 5726181153
FOR ENTIRE SYSTEM

SERVICES
SUB - System Failure Effect Rating $\frac{\sum_{i=1}^{n}[(6) \div (7)]_i}{n}$ = .90

APPENDIX H

WATER SYSTEM COMPOSITE RATING AND DETERMINATION OF CRITICAL OPERATIONS AND COMPONENTS

COMPOSITE RATING

The water supply system rating is a composite of the reliability rating, failure effect rating, ability to meet drinking water standards, and the system design adequacy. An average of the four gives the system rating.

System Reliability Rating, From Page H-2 = 0.54

Water Quality Rating, From Appendix E, Page E-23 = 0.84

Failure Effect Rating, From Page H-9 = 0.90

System Design Adequacy, From Page B-10 = 0.85

Sum = 3.13

System Rating $= \frac{(\text{sum}) \times 100}{4} = \frac{3.13 \times 100}{4}$

System Composite Rating = 78

The rating is expressed as a two-digit number having a value between 0 and 100 with a maximum value of 100.

IDENTIFICATION OF CRITICAL OPERATIONS AND COMPONENTS

Critical operations and components are identified in each of the four rating areas; reliability, ability to meet standards, failure effect, and design adequacy.

Water system reliability. Operation and component criticality with respect to reliability is determined by subtracting the subsystem reliability from one and dividing by one minus the system reliability. The result when multiplied by 100 is the percent contributed by the subsystem to the unreliability (unreliability = 1-reliability) of the system. Like-

Equipment Reliability

Subsystem 11, Obtain Raw Water (Appendix C)

$R_{11} = R_{11}(\text{CREEK}) \times R_{11}(\text{RIVER}) = 0.982 \times 0.983$

Subsystem 12, Treat Raw Water (Appendix D)'

$R_{12} = R_{12}(\text{CREEK}) \times R_{12}(\text{RIVER}) = 0.922 \times 0.921$

Subsystem 13, Distribute Treated Water (Appendix E)

$R_{13} = 0.684$

Subsystem 14, Provide Water Quality Surveillance (Appendix F)

$R_{14} =$ NO EQUIPMENT AFFECTING SYSTEM IF FAILED

Subsystem 15, Provide Services (Appendix G)

$R_{15} = 0.920$

Water System Reliability = R_s = Product of subsystem reliabilities:

$R_s = 0.982 \times 0.983 \times 0.922 \times 0.921 \times 0.684 \times 0.920 = 0.516$

Highest Attainable Reliability for the System (Appendix A, Page A-13)

$R_{HE} + (0.999\cancel{0})^N = (.999)^{37} = 0.9636$

Water System Reliability Rating (Appendix A, Page A-17)

$$\text{System Rating} = \frac{R_s}{R_{HE}} = \frac{0.516}{0.9636} = \underline{\underline{0.54}}$$

Figure H-1. Water System Reliability Study wise, operation unreliability divided by subsystem unreliability gives operation contribution to subsystem unreliability, and component unreliability divided by operation unreliability gives component contribution to operation unreliability. Criticality is defined as the subsystems, operations, and components contributing the greatest unreliability to the system.

The subsystem criticality calculations are made using Table H-1. Operations criticalities are evaluated using Table H-2. Components criticalities are evaluated using Table H-3. Data are obtained from Appendices C, D, E, and G for the reliability criticality analysis. Critical subsystems, operations, and components should be evaluated to determine the best approach to increasing reliability. See pages H-10 through H-17 for the demonstration system.

Water Quality. The identification of constituents which are critical to the ability of the system to meet the drinking water standards is determined by the relative contribution of each constituent rating to the rating of system ability. The relative contribution is obtained from column (5) of Figure B-6, Appendix B, (used in Appendices C, D, and E), for the distribution subsystem.

Failure Effects. Operation failure effect criticality is defined as those operations that, if failed, would cause the greatest effect on the ability of the water system to furnish water meeting drinking water standards. Those operations having a low rating in the failure effect computation are critical. The operations would be those having a rating of less than one from column (8) of Table A-5, Appendix A (used in each Appendix). Relative criticality is determined by the lowness of the rating in column (8); a 1.00 rating is the highest and 0 the smallest. Critical operations should be evaluated to determine the best approach to increase reliability and decrease potential failure effects.

Design Adequacy. The design adequacy measures the ability of the system to remove excess concentrations of constituents or determine if the subsystems are contaminating the water. Criticality is based on the design adequacy of the treatment and distribution subsystems relative to

TABLE H-1. SUBSYSTEM CRITICALITY COMPUTATION

System Name ____________________

System Unreliability = $1 - R_s = 1 -$ ____ = ______

Subsystem Identification	Subsystem Reliability Rxx	Subsystem Unreliability 1-Rxx	Criticality $\frac{1-Rxx}{1-Rs}$	Remarks

TABLE H-2. OPERATIONS CRITICALITY COMPUTATION

Subsystem Name ____________________

Subsystem Identification Number ____________

Subsystem Unreliability = 1-Rxx = 1-____ = _____

Operation Identification	Operation Reliability Rxxxxx	Operation Unreliability 1-Rxxxxx	Criticality $\frac{1\text{-}Rxxxxx}{1\text{-}Rxx}$	Remarks

TABLE H-3. COMPONENTS CRITICALITY COMPUTATION

Operation Name ____

Operation Identification Number ____________________

Operation Unreliability = 1-Rxxxxx = 1- _____ = ______

Component Identification	Component Reliability R_c	Component Unreliability $1-R_c$	Criticality $\frac{1-R_c}{1-Rxxxxx}$	Remarks

excess constituent concentrations. The evaluation should be correlated with water quality data to determine if the excess constituents are present in raw water, if satisfactory treatment is provided to remove the constituents (if removable by treatment methods), and if the constituent is added during treatment and distribution.

Criticality Analysis. Evaluating the various critical subsystems, operations, and components should lead to recommendations for improving system design, reliability, operation, and control. The analysis should result in recommendations to increase the ability of the water system to meet the constituent limits of the drinking water standards.

TABLE A-5. OPERATION RELATIVE FAILURE EFFECT

(1) Operation Number (From Table F-2)	(2) Failure Effect Weighting Factor, F (From Table F-4)	(3) Operation Weight Factor Fraction $1-(F_i \div \sum_{i=1}^{n} F_i)$	(4) Actual Operation Reliability, R_i (From Table F-2)	(5) Highest Operation Achievable Reliability, R_h	(6) Actual Operation Failure Effect (3) x (4)	(7) Lowest Operation Failure Effect (3) x (5)	(8) Operation Rating (6) ÷ (7)
SUB-SYSTEM							
11	From page C-23,			10 OPERATIONS			8.98
12	From page D-38,			22 OPERATIONS			21.80
13	From page E-21,			11 OPERATIONS			10.01
14	From page F-5,			5 OPERATIONS			2.65
15	From page G-13,			12 OPERATIONS			10.76
SYSTEM SUMMATION				60 OPERATIONS			54.20
FAILURE EFFECTS SYSTEM RATING = $\frac{54.20}{60}$ = .90							

Summation, $\sum_{i=1}^{n} F_i$ = 5726181153
FOR ENTIRE SYSTEM

System Failure Effect Rating $\frac{\sum_{i=1}^{n}[(6) \div (7)]_i}{n}$ = .90

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TABLE H-I. SUBSYSTEM CRITICALITY COMPUTATION

System Name Demonstration System

System Unreliability = $1-R_s = 1-.54 = .46$

Subsystem Identification	Subsystem Reliability Rxx	Subsystem Unreliability 1-Rxx	Criticality $\frac{1-Rxx}{1-Rs}$	Remarks
11	.982x.983= .96	.04	.09	
12	.922x.921= .85	.15	.33*	
13	.68	.32	.70*	
15	.92	.08	.17	

*Treatment and distribution (subsystems 12 and 13) are most critical subsystems.

TABLE H-2. OPERATIONS CRITICALITY COMPUTATION

Subsystem Name Treat Raw Water

Subsystem Identification Number 12

Subsystem Unreliability = 1-Rxx = 1-.85 = .15

Operation Identification	Operation Reliability Rxxxxx	Operation Unreliability 1-Rxxxxx	Criticality $\frac{1-Rxxxxx}{1-Rxx}$	Remarks
Creek Source:				
12122	.996	.004	.027	
1222	.986	.014	.093 *	
12231	.985	.015	~~.010~~ .100 *	
12242	.999	.001	.006	
12331	.992	.008	.053	
12332	.996	.004	.027	
River Source:				
12111	.996	.004	.027	
12122	.997	.003	.020	
1222	.965	.035	.233 *	
12231	.973	.027	.180 *	
12242	.997	.003	.020	
12321	.998	.002	.013	
12331	.992	.008	.053	
12332	.994	.006	.040	

* Critical Unit Operations

TABLE H-3. COMPONENTS CRITICALITY COMPUTATION

Operation Name Add Chemicals, Rapid Mix, Coagulate, & Settle, Creek Source

Operation Identification Number 1222 – Creek

Operation Unreliability = 1-Rxxxxx = 1- .986 = .014

Component Identification	Component Reliability R_c	Component Unreliability $1-R_c$	Criticality $\frac{1-R_c}{1-Rxxxxx}$	Remarks
Lime Feed	.9963	.0037	.264 *	
Alum Feed	.9999	.0001	.007	
Carbon Feed	.9999	.0001	.007	
Drain Valves	.9998	.0002	.014	
Mixing Tank	.9983	.0017	.121 *	
Sedimentation Basin	.993	.007	.500 *	
Sluice Gates	.9996	.0004	.029	

*Critical Components

TABLE H-3. COMPONENTS CRITICALITY COMPUTATION

Operation Name Filter with Gravity Filter -- Creek Source

Operation Identification Number 12231

Operation Unreliability = 1-Rxxxxx = 1- .985 = .015

Component Identification	Component Reliability R_c	Component Unreliability $1-R_c$	Criticality $\frac{1-R_c}{1-Rxxxxx}$	Remarks
Filters	1-	0	0	
Manual Valves	.9996	.0004	.027	
Filter Sweeps	.992	.008	.533*	
Washwater Valves	.994	.006	.400*	
Pipe	.9989	.011	.733*	
Common Walls	.999	.001	.067	

*Critical Components

TABLE H-3. COMPONENTS CRITICALITY COMPUTATION

Operation Name Add Chemicals, Rapid Mix, Coagulate, Settle - River

Operation Identification Number 1222 River

Operation Unreliability = 1-Rxxxxx = 1-.965 = .035

Component Identification	Component Reliability R_c	Component Unreliability $1-R_c$	Criticality $\frac{1-R_c}{1-Rxxxxx}$	Remarks
Alum Feed	.9919	.0081	.231*	
NALCO Feed	.9919	.0081	.231*	
Agitator Mixer	.9987	.0013	.037	
Mix Basin	.9983	.0017	.049	
Flocculator	.9691	.0309	.883*	
Settling Basin	.996	.004	.114*	
Pipe	.9989	.0011	.031	
⋮				

*Critical Components

TABLE H-3. COMPONENTS CRITICALITY COMPUTATION

Operation Name Filter with Gravity Filter – River

Operation Identification Number 12231 -- River

Operation Unreliability = 1-Rxxxxx = 1- .973 = .027

Component Identification	Component Reliability R_c	Component Unreliability $1-R_c$	Criticality $\frac{1-R_c}{1-Rxxxxx}$	Remarks
Filters	.996	.004	.148*	
Filter Sweeps	.992	.008	.296*	
Basin	.996	.004	.148*	
Control Valves	.996	.004	.148*	
Rate Controller	.9996	.0004	.015	
Manual Valves	.9999	.0001	.004	
Washwater Pumps	.996	.004	.148*	
Pipe	.9989	.0011	.041	
Common Walls	.9998	.0002	.007	

*Critical Components

TABLE H-2. OPERATIONS CRITICALITY COMPUTATION

Subsystem Name Distribute Treated Water

Subsystem Identification Number 13

Subsystem Unreliability = 1-Rxx = 1-.68 = .32

Operation Identification	Operation Reliability Rxxxxx	Operation Unreliability 1-Rxxxxx	Criticality $\frac{1-Rxxxxx}{1-Rxx}$	Remarks
13111	.995	.005	.02	
13111, 13112, 13122, 13122	.704	.296	.92 *	
13211	.991	.009	.03	

* Gravity feed and pump feed are most critical (second line entry composed of 13111, 13112, 13122, 13122).

TABLE H-3. COMPONENTS CRITICALITY COMPUTATION

Operation Name Gravity and Pump Feed the Demand and Storage -- Distribution

Operation Identification Number 13111, 13112, 13122, 13122

Operation Unreliability = 1-Rxxxxx = 1- .70 = .30

Component Identification	Component Reliability R_c	Component Unreliability $1-R_c$	Criticality $\frac{1-R_c}{1-Rxxxxx}$	Remarks
Pumps, High Lift	1-	0	0	
Valves, Manual	.8926	.1074	.36 *	
Valves, Check	.9940	.0060	.02	
Pipe, Process	.9967	.0033	.01	
Electric Power	.9971	.0029	.01	
Recorders	.9781	.0119	.04	
Valves, Control	.998	.002	.01	
Looped Distribution Mains	.96	.04	.13 *	
Dead-End Mains	.96	.04	.13*	
Fire Hydrants	.889	.111	.37*	
Pumps, Booster	.9998	.0002	0	

*Critical Components

APPENDIX I

WATER SYSTEM FAILURE MODES AND EFFECTS ANALYSIS

A failure modes and effects analysis was performed to define all physical, operational, and surveillance components of urban water systems that have, or may have, an effect on the ability of the total water supply system to produce water of a given quality. A failure modes and effects analysis is a systematic method of determining the consequences of unit operation failure with respect to system operation. The analysis results in the identification of components which are critical to satisfactory system performance.

The failure modes and effects analysis is performed for each unit operation of each subsystem in the water system. Unit operations in water systems were structured by subsystems. A matrix is provided to insure examination of all components of water systems. The following definitions apply to column headings used in the failure modes and effects analysis:

1. Component and number - Name and identification number of components and unit operations
2. Component function - Description of design function to be performed by the component or unit operation
3. Failure mode - Description of failures which occur to component or unit operation
4. Failure effect - Identification of effect on system and water quality caused by the failure mode of the component or unit operation
5. Detection means - Description of methods which can be used to identify the possible occurrence of the failure
6. Remarks - Comments and other considerations related to component or unit operation design, installation, inspection, operation, and maintenance

The failure modes and effects analysis defines design, operation, maintenance, and surveillance criteria which should be considered in evaluating and rating water supply systems. It is provided to assist in identification of water system characteristics which are critical to the ability of a water system to consistently supply water meeting the constituent limits of Federal Drinking Water Standards.

The failure modes and effects analyses are included for each subsystem on the following figures and pages:

Subsystem 11 - Obtain raw water, Figures I-1 and I-2, Pages I-3 through I-22

Subsystem 12 - Treat raw water, Figures I-3 and I-4, Pages I-23 through I-40

Subsystem 13 - Distribute treated water, Figures I-5 and I-6, Pages I-41 through I-47

Subsystem 14 - Provide water quality surveillance, Figures I-7 and I-8, Pages I-48 through I-50

Subsystem 15 - Provide services, Figures I-9 and I-10, Pages I-51 through I-57

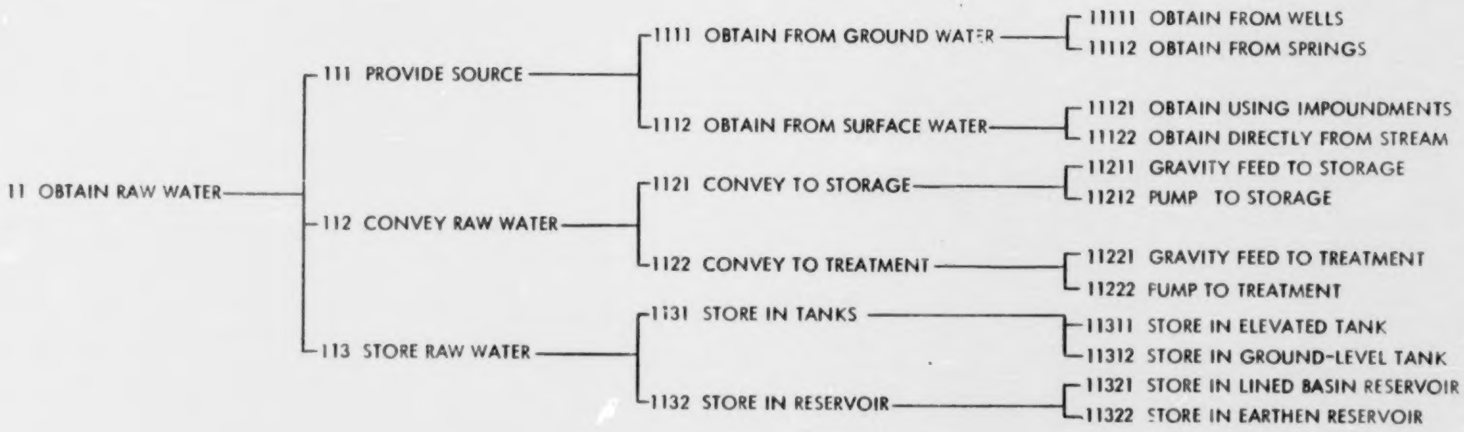
11 OBTAIN RAW WATER
111 PROVIDE SOURCE
112 CONVEY RAW WATER
113 STORE RAW WATER
1111 OBTAIN FROM GROUND WATER
1112 OBTAIN FROM SURFACE WATER
1121 CONVEY TO STORAGE
1122 CONVEY TO TREATMENT
1131 STORE IN TANKS
1132 STORE IN RESERVOIR
11111 OBTAIN FROM WELLS
11112 OBTAIN FROM SPRINGS
11121 OBTAIN USING IMPOUNDMENTS
11122 OBTAIN DIRECTLY FROM STREAM
11211 GRAVITY FEED TO STORAGE
11212 PUMP TO STORAGE
11221 GRAVITY FEED TO TREATMENT
11222 PUMP TO TREATMENT
11311 STORE IN ELEVATED TANK
11312 STORE IN GROUND-LEVEL TANK
11321 STORE IN LINED BASIN RESERVOIR
11322 STORE IN EARTHEN RESERVOIR

Figure I-1. Structure and Matrix of Water Source

(sheet 1 of 19)

Operation Name: Supply Raw Water From Wells

Operation Number: 11111000

Subfunction: Supply From Groundwater 11110000 Function: 11100000 Provide Raw Water Source Subsystem: 11000000 Obtain Raw Water

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Well Screen 11111001	Screen out sand and other solids from water.	Collapse of screen. Clogging by bacteria growth or mineral buildup.	Sand/solids in water prevent flow from well and possible screen callapse.	Increased turbidity of raw water increased sand/ solids in raw water.	Screens should be replaced at failure.
Well Casing or Pit 11111002	Prevent intrusion of contaminated higher level water into aquifer. Provide casing into which drop pipe is lowered for removing water. Casing should be sealed to impermeable layer.	Leakage of contaminated water into well.	Increased bacteriological or chemical contamination of water and aquifer.	Testing raw water for increased bacteria and chemical constituents. Pressure testing of well.	Bacterial contamination most prevalent. Well location has bearing on contamination. Considerations include: 1. Well at high point of land. 2. Located at least the maximum distance from pollution sources that economics, land ownership, geology, topography will permit. 3. Survey location with respect to caves, sink holes, abandoned wells/bores, fissures, faults, over the aquifer.

Figure I-2. Component Failure Modes and Effects Analysis

(sheet 2 of 19)

Operation Name: Supply Raw Water From Wells
Operation Number: 11111000
Subfunction: Supply From Groundwater 11110000 Function: 11100000 Provide Raw Water Source Subsystem: 11000000 Obtain Raw Water

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Well Cap 11111003	Seal casing to prevent surface contamination and to drain surface contamination away from well head. Cap provided with vent to maintain atmospheric pressure in casing.	Leakage of contaminated water into well. Vent flooded and contaminates well.	Increased bacteriological or chemical contamination of water and aquifer.	Testing raw water source for bacteria and chemical constituents changes/ increases. Pressure testing of well.	-
Pipe 11111004	Constrain water and convey from aquifer to surface. Prevents intrusion of contamination from external sources.	Leakage of contamination into water. Requires loss of pressure in pipe. Leakage reduces quantity supplied.	Increased bacteria contamination of water. Loss of water.	Pressure drop in source supply pipe. Decreased flow from well. Test for increased bacteria concentration.	
Check Valve or Foot Valve 1111005	Prevent loss of pump prime and drop in water column in drop pipe. Prevent backflow to well.	Failed to open. Shattering due to back pressure.	Possible loss of pump prime. Back flow to well and loss of pressure. Possible contamination of aquifer if water in pipe is contaminated.	Back flow through pump and well. Loss of pressure from well supply.	

Figure I-2. (Continued)

(sheet 3 of 19)

Operation Name: Supply Raw Water From Wells
Operation Number: 11111000
Subfunction: Supply From Groundwater 11110000 Function: Provide Raw Water Source 11100000 Subsystem: Obtain Raw Water 11000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Flow Meter 11111006	Measure output.	No indication or record of output.	Loss of output record. No effect to water quality.	Recorder or indicator not functioning. No quality effects.	In cases where meter is part of control circuit, other sources might be started.
Line Stop Valves 11111007	Normally open. Used to manually isolate well from system.	Leakage. Failed to open.	Negligible loss of ability to isolate well. No water quality effects.	Manual check of valve operation.	
Pump 11111008	Withdraw water from aquifer and supply under pressure to system.	Pump or driver failure.	Loss of pressure. No water quality effects.	Pressure drop.	Alarms should be used for pressure loss.

Figure I-2. (Continued)

(sheet 4 of 19)

Operation Name: Supply Raw Water From Springs or From Infiltration Galleries

Operation Number: 11112000

Subfunction: Supply From Groundwater 11110000 Function: Provide Raw Water Source 11100000 Subsystem: Obtain Raw Water 11000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Spring Box 11112001	Collection of gravity spring water or artesian water and protection from surface contamination.	Inflow of contaminated water.	Contamination of water supply.	Testing raw water for chemical and bacterial content.	Artesian sources are at higher head than surface and are less subject to contamination than gravity springs which occur from water table outflow. The water source (recharge point) for springs must be surveyed and protected from contamination.
Air Vent 11112002	Maintain atmospheric pressure in spring box.	Flooding.	Contamination of water.	Testing raw water for bacterial content.	Vent should be inverted, screened (#24 mesh), and 18 inches above surface.
Spring Screen 11112003	Prevent intake of sand and other solids.	Collapse of screen. Clogging of screen.	Sand and other solids are taken into system clogging and stopping flow.	Increase in solids in water. Loss of flow.	
Flow Meter 11112004	See 11111006				
Check Valve 11112005	Prevent back flow to spring.	Failed to open.	Back flow to spring.	Pressure loss.	

Figure I-2. (Continued)

(sheet 5 of 19)

Operation Name: Supply Raw Water From Springs or From Infiltration Galleries
Operation Number: 11112000
Subfunction: Supply From Groundwater 11110000 Function: Provide Raw Water Source 11100000 Subsystem: 11000000 Obtain Raw Water

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Line Stop Valve 11112006	Normally open. used to isolate part of system or for manual flow control.	Leakage. Failed open.	Negligible loss of ability to isolate part of system or to manually control flow.	Manual check of valve operation.	
Pipe 11112007	See 11111004				

Figure I-2. (Continued)

(sheet 6 of 19)

Operation Name: Supply Raw Water From Impoundment

Operation Number: 11121000

Subfunction: Supply From Surface Water 11120000 Function: Provide Raw Water Source 11100000 Subsystem: 11000000 Obtain Raw Water

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Line Stop Valve 11121001	Opened or closed to allow intake of water at various heights in the reservoir due to water level or turbidity.	Seizure. Leakage.	Seizure causes inability to adjust valve or open or close. Leakage prevents complete close off of an intake. Either mode may cause difficulty in controlling intake of turbidity or surface contamination in the reservoir.	Manually check valve operation. Close and check for leakage.	
Control Valve 11121002	Control flow of raw water from reservoir usually from remote point such as the filter plant.	Erratic Control. Seizure. Leakage.	Controls or actuator failure, seizure prevents movement of valve. Either mode prevents flow control and inability to shut off supply if necessary to prevent intake of excessively contaminated water.	Periodic calibration and verification. Operate valve through open to close positions on a periodic basis.	

Figure I-2. (Continued)

(sheet 7 of 19)

Operation Name: Supply Raw Water From Impoundment

Operation Number: 11121000

11000000 ·

Subfunction: Supply From Surface Water 11120000 Function: Provide Raw Water Source 11100000 Subsystem: Obtain Raw Water

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Reservoir 11121003	Store raw water and protect it from further contamination, and provide excess storage for periods of low rainfall, runoff, and collection.	Contamination from external sources such as industry, sewage, habitation, wastewater. Contamination from internal sources such as recreation, overgrowth in aquatic vegetation, reduced oxygen content.	Excessive contamination of impoundment which may overload treatment and disinfection. Taste and odor are detrimentally affected.	Water sampling and testing of all source areas of impoundment contamination. Survey of impoundment. Control and legal authority required to prevent contamination from external sources.	Reservoirs provide excess storage to provide water to source during low flow periods. Raw water reserviors are particularly subject to algal buildups requiring copper sulfate treatment. Note that water may be purchased from external reservoir owner.
Dike or Dam 11121004	Contain water in the impoundment and provide structure for gatehouse and overflow.	Break in dam.	Loss of water supply.	Storm control of water level by prior warning. Inspection of dam to assure integrity.	
Pipe 11121005	Confine water and transport it through dam to point of conveyance to treatment.	Leakage or rupture. Contamination by trace metals.	Loss of water and possible serious damage to dam. Contamination of water.	Pipe inspection periodically, use of proper materials prevents contamination by trace metals.	

Figure I-2. (Continued)

(sheet 8 of 19)

Operation Name: Supply Raw Water From Impoundment
Operation Number: 11121000
Subfunction: Supply From Surface Water 11120000 Function: Provide Raw Water Source 11100000 Subsystem: 11000000 Obtain Raw Water

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Screen, Bar 11121006	Prevent intake of debris from impoundment.	Break in screen, dislodging, clogging.	Intake of debris. Loss of water supply.	Inspection and cleaning of screens.	

Figure I-2. (Continued)

(sheet 9 of 19)

Operation Name: Supply Raw Water From Streams

Operation Number: 11122000

Subfunction: Supply From Surface Water 11120000 Function: Provide Raw Water Source 11100000 Subsystem: Obtain Raw Water 11000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Cross or Side Intake Weir 11122001	Funnel or channel water to an intake location and provide a source of low velocity with sufficient depth.	Break in weir.	Loss of source of low velocity which may increase turbidity and susceptibility of intake of debris.	Periodic inspection of weir.	
Fixed Screen 11122002	Prevent intake of large debris such as logs.	Break or dislodgement of screen. Clogging.	Possible intake of large debris which would damage other intake components. Clogging prevents passage of water.	Inspection of screen.	
Traveling Screen 11122003	Remove fine debris such as vegetation, leaves, fish.	Break in screen. Clogging of screen due to excess debris or vegetation.	Possible intake of debris which would trouble treatment processes. Loss of water supply until screen is cleaned.	Inspection of screen operation.	Washwater flow adjustment is critical to removal of debris.
Intake pipe or Tunnel 11122004	Confine water and convey it through intake structure.	Break or leakage. Contamination of water by trace metal in pipe.	Damage to intake structure. Loss of water supply. Contamination of water.	Inspection of pipe periodically. Proper choice of materials prevents contamination by trace metals.	

Figure I-2. (Continued)

(sheet 10 of 19)

Operation Name: Supply Raw Water From Streams

Operation Number: 11122000

Subfunction: Supply From Surface Water 11120000 Function: Provide Raw Water Source 11100000 Subsystem: Obtain Raw Water 11000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Line Stop Valve, Intake Gate 11122005	Isolate intake from source. Manual control of intake flow in emergencies.	Seizure. Leakage.	Seizure prevents valve operation and loss of ability to control intake in emergencies. Leakage prevents isolation of intake from source.	Periodically open and shut valve to check operation. Check for leakage.	
Check Valve 11122006	Prevent back flow of water.	Fail open.	Back flow may cause loss of water supply.	Periodically check valve operation.	
Screen Wash-water Pump 11122007	Provide water to wash debris from screens.	Loss of pressure.	Clogging of screens, nonremoval of debris, debris taken into system.	Alarms. Periodically inspect pump operation.	Provide standby pumps.
Stream 11122008	Source of supply.	Excess contamination by bacteria, vegetation (taste and odor). Chemicals, low flow. Transportation accidents (autos, trains) which may cause source contamination.	Contamination of water. Low flow causes loss of supply Contamination of source.	Test water. Survey stream and control sources of contamination. Set up early warning system to prevent intake of water which is beyond capability of removal by treatment. Transportation safety system. Water utility should be on the list of those to be notified in case of accident in the watershed.	Control of industrial and other contamination is necessary.

Figure I-2: (Continued)

(sheet 11 of 19)

Operation Name: Convey Raw Water to Storage by Gravity

Operation Number: 11211000

Subfunction: Convey to Storage 11210000 Function: Convey Raw Water 11200000 Subsystem: Obtain Raw Water 11000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Pipe or Conduit 11211001	Confine and direct raw water flow.	Rupture. Leakage. Contamination by trace metals.	Loss of water. Trace metal contamination may cause failure of water system.	Periodically inspect pipe. Test water for trace metal contamination. Proper design and materials should prevent contamination. Pressure test for leaks.	
Line Stop Valves 11211002	Isolate portions of pipe for repair or testing. Emergency flow control.	Fail open by seizure. Leakage.	Loss of isolation capability. Leakage causes loss of water.	Manually operate valves periodically. Pressure test for leaks.	
Control Valves 11211003	Control flow from remote station.	Improper response to signal. Seizure. Leakage.	Loss of control.	Calibrate and verify valve operation. Pressure test pipe and valves.	
Flow Meter 11211004	Indicate water flow for control of flow to meet water demand.	Nonindication of flow.	Loss of visual means to measure flow.	Visual. Compare various flow meters. Inspect and calibrate.	
Outflow Structure 11211005	Provide connection to pipe.	Leakage.	Loss of water leakage into structure may possibly contaminate water.	Inspection of surfaces.	

Figure I-2. (Continued)

(sheet 12 of 19)

Operation Name: Convey Raw Water to Storage by Pumping
Operation Number: 11212000
Subfunction: Convey to Storage 11210000 Function: Convey Raw Water 1120000 Subsystem: Obtain Raw Water 11000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Check Valve 11212001	Prevent Back flow to pump.	Fail open. Leakage.	Loss of pressure when pump not operating. Back flow of water.	Periodically check operation.	
Line Stop Valves 11212002	Isolate pump from pipe.	Fail open. Leakage.	Loss of capability to isolate pump if check valve also fails. A safety hazard would occur if only the check valve were allowed to hold pipe pressure.	Periodically open and shut valves and check operation. Pressure test for leaks.	
Pumps 11212003	Provide energy to move water.	Loss of capacity through pump failure.	Loss of capacity and pressure (if all pumps fail). Loss of pressure allows inflow of possible contamination in system.	Periodically inspect pumps. Pump failure indicated by annunciator system.	
Housing Structure 11212004	Protect pumps from elements and provide foundation for pumps.	Leakage.	Loss of protection to pumps, if severe exposure results.	Inspection of housing structure.	
Control Valves 11212005	Provide flow control from remote station.	Error response. Leakage. Seizure.	Control loss of positive shut-off ability. Loss of operation.	Calibration and testing of valve operation. Pressure test for leakage.	
Flow Meter 11212006	Same as 11211004				
Pipe or Conduit 11212007	Same as 11211001				
Outflow Structure 11212008	Same as 11211005				

Figure I-2. (Continued)

(sheet 13 of 19)

Operation Name: Convey Raw Water to Treatment by Gravity

Operation Number: 11221000

Subfunction: Convey to Treatment 11220000 Function: Convey Raw Water 11200000 Subsystem: Obtain Raw Water 11000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Pipe or Conduit 11221001	Same as 11211001				
Line Stop Valves 11221002	Same as 11211002				
Control Valve 11221003	Same as 11211003				
Flow Meter 11221004	Same as 11211004				

Figure I-2. (Continued)

(sheet 14 of 19)

Operation Name: Convey Raw Water to Treatment by Pumping
Operation Number: 11222000
Subfunction: Convey to Treatment 11220000 Function: Convey Raw Water 11200000 Subsystem: Obtain Raw Water 11000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Check Valve 11222001	Same as 11212001				
Line Stop Valves 11222002	Same as 11212002				
Pumps 11222003	Same as 11212003				
Housing Structure 11222004	Same as 11212004				
Control Valve 11222005	Same as 11212005				
Flow Meter 11222006	Same as 11211004				
Pipe or Conduit 11222007	Same as 11211001				

Figure I-2. (Continued)

Operation Name: Store Raw Water in Elevated Tanks

(sheet 15 of 19)

Operation Number: 11311000

Subfunction: Store in Tanks 11310000 Function: Store Raw Water 11300000 Subsystem: Obtain Raw Water 11000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Pipe, Inflow 11311001	Same as 11211001				
Tank 11311002	Confine and store raw water. Storage also provides some plain settling. Storage gives excess supply to meet demand when source flow is low.	Rupture of tank. Leakage. Contamination by dissolving trace metals from tank materials. Algal growth can be a problem in an open tank.	Loss of stored water. Possible loss of supply if tank is not bypassed. Contamination of water may cause system to fall below trace metal standards. Taste and odor.	Periodic inspection, pressure testing, and coating of tank with noncontaminating coating. Proper materials and construction should prevent contamination by trace metals. Contamination detected by testing water.	
Level Recorder 11311003	Provide visual display of stored water volume and control feed.	Failure to record or to properly regulate water level.	Loss of visual display. Possible under- or overfilling with water. Under-filling may result in loss of excess supply or even loss of supply.	Comparison of level recorder readings with equivalent head or pressure indicators. Inspection, calibration, and verification of proper operation should be periodically performed.	
Line Stop Valves 11311004	Isolate fill pipe or tank for inspection or repair and for emergency flow control.	Fail open by seizure. Leakage.	Loss of isolation capability.	Manually operate valves periodically. Pressure test for leaks.	
Control Valve, Altitude Valve 11311005	Control amount of stored water by head pressure.	Improper response to control signal. Seizure. Leakage.	Loss of level control (automatic).	Calibrate and verify proper operation. Pressure test for leaks.	

Figure I-2. (Continued)

(sheet 16 of 19)

Operation Name: Store Raw Water in Elevated Tanks

Operation Number: 11311000

Subfunction: Store in Tanks 11310000 Function: Store Raw Water 11300000 Subsystem: Obtain Raw Water 11000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Level Controller 11311006	Control signals to altitude valve to preset conditions of water level.	Improper setting or malfunction of signal circuit.	Loss of automatic level control.	Calibrate and verify proper operation and setting of controls.	

Figure I-2. (Continued)

(sheet 17 of 19)

Operation Name: Store Raw Water in Ground Level Tanks

Operation Number: 11312000

Subfunction: Store in Tanks 11310000 Function: Store Raw Water 11300000 Subsystem: Obtain Raw Water 11000000

Component & Number	Component Function	Failure Modes	Failure Effect	Detection Means	Remarks
Pipe, Inflow 11312001	Same as 11211001				
Tank 11312002	Same as 11311002				
Level Recorder 11312003	Same as 11311003				
Line Stop Valves 11312004	Same as 11311004				
Control Valve 11312005	Same as 11311005				
Level Controller 11312006	Same as 11311006				

Figure I-2. (Continued)

(sheet 18 of 19)

Operation Name: Store Raw Water in Lined Reservoir
Operation Number: 11321000
Subfunction: Store in Reservoir 11320000 Function: Store Raw Water 11300000 Subsystem: Obtain Raw Water 1100000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Reservoir, Lined, Covered 11321001	Confine and store raw water. Provide excess supply when source flow is low. Provides some plain settling.	Break in reservoir. Contamination from external source. Sedimentation buildup.	Loss of water. Excessive contamination of raw water. Loss of storage capacity.	Inspection. Test water. Inspect sediment depth. Ownership and protection of area surrounding reservoir is necessary.	
Line Stop Valves 11321002	Isolate reservoir for inspection, cleaning, and repair. Emergency flow control.	Fail open by seizure. Leakage.	Loss of isolation capability.	Manually operate valves periodically. Pressure test for leaks.	
Control Valve, Altitude Valve 11321003	Same as 11311005				
Level Recorder 11321004	Same as 11311003				
Pipe, Inflow 11321005	Same as 11311001				
Level Controller 11321006	Same as 11311006				

Figure I-2. (Continued)

Operation Name: Store Raw Water in Earthen Reservoir (sheet 19 of 19)

Operation Number: 11322000

Subfunction: Store in Reservoir 11320000 Function: Store Raw Water 11300000 Subsystem: Obtain Raw Water 11000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Reservoir, Earthen 11322001	Same as 11321001				
Line Stop Valves 11322002	Same as 11321002				
Control Valves, Altitude Valve 11322004	Same as 11311005				
Level Recorder 11322004	Same as 11311003				
Pipe, Inflow 11322005	Same as 11311001				
Level Recorder 11322006	Same as 11311006				

Figure I-2. (Continued)

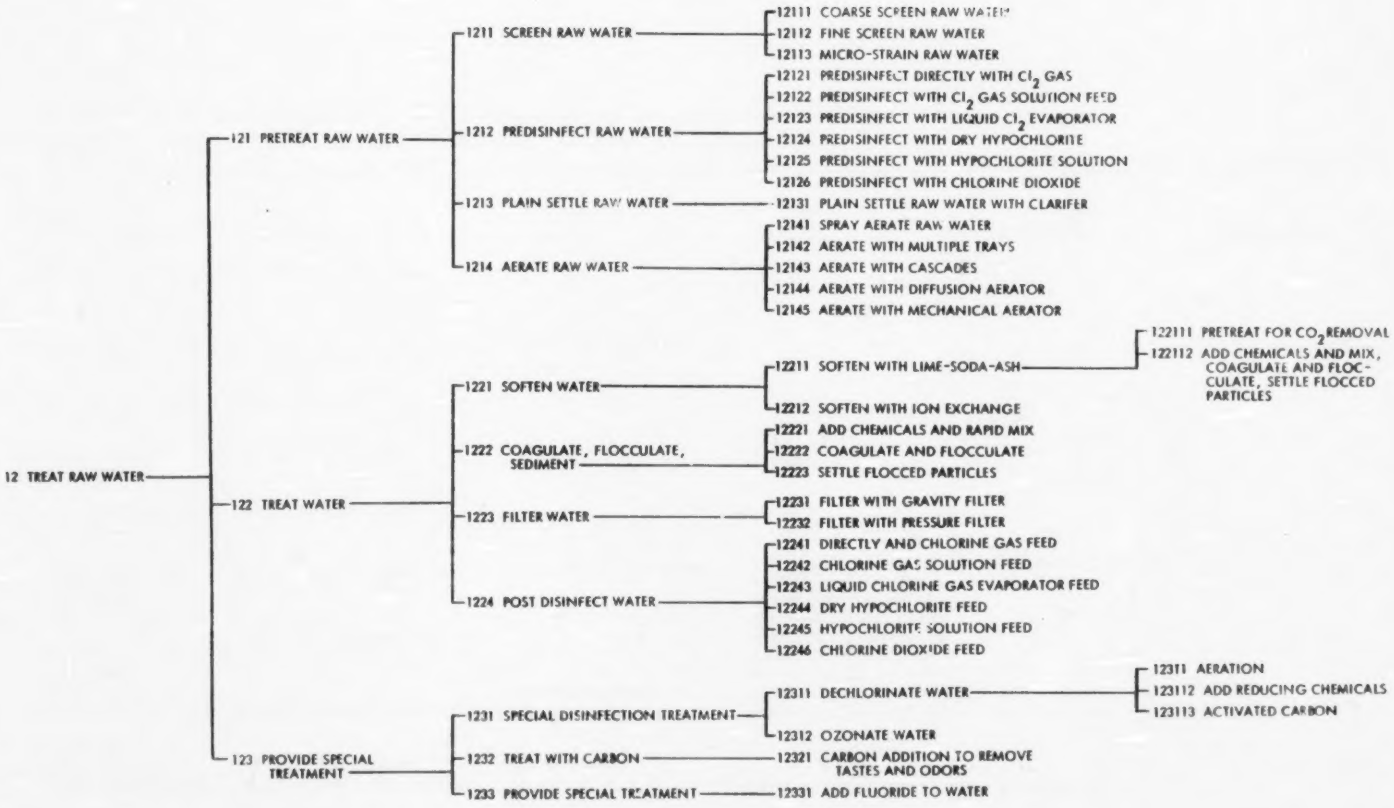
12 TREAT RAW WATER
121 PRETREAT RAW WATER
1211 SCREEN RAW WATER
12111 COARSE SCREEN RAW WATER
12112 FINE SCREEN RAW WATER
12113 MICRO-STRAIN RAW WATER
1212 PREDISINFECT RAW WATER
12121 PREDISINFECT DIRECTLY WITH Cl_2 GAS
12122 PREDISINFECT WITH Cl_2 GAS SOLUTION FEED
12123 PREDISINFECT WITH LIQUID Cl_2 EVAPORATOR
12124 PREDISINFECT WITH DRY HYPOCHLORITE
12125 PREDISINFECT WITH HYPOCHLORITE SOLUTION
12126 PREDISINFECT WITH CHLORINE DIOXIDE
1213 PLAIN SETTLE RAW WATER
12131 PLAIN SETTLE RAW WATER WITH CLARIFER
1214 AERATE RAW WATER
12141 SPRAY AERATE RAW WATER
12142 AERATE WITH MULTIPLE TRAYS
12143 AERATE WITH CASCADES
12144 AERATE WITH DIFFUSION AERATOR
12145 AERATE WITH MECHANICAL AERATOR
122 TREAT WATER
1221 SOFTEN WATER
12211 SOFTEN WITH LIME-SODA-ASH
122111 PRETREAT FOR CO_2 REMOVAL
122112 ADD CHEMICALS AND MIX, COAGULATE AND FLOCCULATE, SETTLE FLOCCED PARTICLES
12212 SOFTEN WITH ION EXCHANGE
1222 COAGULATE, FLOCCULATE, SEDIMENT
12221 ADD CHEMICALS AND RAPID MIX
12222 COAGULATE AND FLOCCULATE
12223 SETTLE FLOCCED PARTICLES
1223 FILTER WATER
12231 FILTER WITH GRAVITY FILTER
12232 FILTER WITH PRESSURE FILTER
1224 POST DISINFECT WATER
12241 DIRECTLY AND CHLORINE GAS FEED
12242 CHLORINE GAS SOLUTION FEED
12243 LIQUID CHLORINE GAS EVAPORATOR FEED
12244 DRY HYPOCHLORITE FEED
12245 HYPOCHLORITE SOLUTION FEED
12246 CHLORINE DIOXIDE FEED
123 PROVIDE SPECIAL TREATMENT
1231 SPECIAL DISINFECTION TREATMENT
12311 DECHLORINATE WATER
12311 AERATION
123112 ADD REDUCING CHEMICALS
123113 ACTIVATED CARBON
12312 OZONATE WATER
1232 TREAT WITH CARBON
12321 CARBON ADDITION TO REMOVE TASTES AND ODORS
1233 PROVIDE SPECIAL TREATMENT
12331 ADD FLUORIDE TO WATER

Figure I-3. Structure and Matrix for Raw Water Treatment, Subsystem 12

Operation Name: Coarse Screen Raw Water

(sheet 1 of 17)

Operation Number: 12111000

Subfunction: Screen Raw Water 12110000 Function: Pretreat Raw Water 12100000 Subsystem: Treat Raw Water 12000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Intake and Outflow Structure 12111001	Confine raw water to flowing through screen.	Break or leak in structure.	Loss of water screening.	Inspection.	
Fixed Screen, Bar Grille 12111002	Remove debris from water.	Clogged deterioration or breakthrough.	Loss of screening capability. Clogging causes loss of water supply. Taste and color problems might occur if leaves or other vegetation decompose in sufficient quantity.	Inspection of reservoir and screens.	

Figure I-4.. Component Failure Modes and Effects Analysis

(sheet 2 of 17)

Operation Name: Fine Screen Raw Water

Operation Number: 12112000

Subfunction: Screen Raw Water 12110000 Function: Pretreat Raw Water 12100000 Subsystem: Treat Raw Water 12000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Intake and Outflow Structure 12112001	Same as 12111001				
Traveling Screen 12112002	Remove fine debris such as vegetation, leaves.	Same as 11122003			
Washwater Pump 12112003	Same as 11122007				
Check Valve 12112004	Same as 11212001				
Line Stop Valves 12112005	Same as 11212002				
Washwater Jets and Pipe 12112006	Spray water to remove debris from screen	Clogged jets or pipe.	Clogged screen. Increased turbidity.	Inspection. Test of water.	
Control Valves 12112007	Same as 11212005				

Figure I-4. (Continued)

(sheet 3 of 17)

Operation Name: Micro-Strain Raw Water

Operation Number: 12113000

Subfunction: Screen Raw Water 1211000 Function: Pretreat Raw Water 12100000 Subsystem: Treat Raw Water 12000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Intake and Outflow Structure 12113001	Same as 12111001				
Traveling, Drum, or Band Strainer 12113002	Same as 12112002				
Washwater Pump 12113003	Same as 11122007				
Check Valve 12113004	Same as 11212001				
Line Stop Valves 12113005	Same as 11212002				
Washwater Jets, Piping 12113006	Same as 12112006				
Control Valves 12113007	Same as 11212005				
Drains 12113008	Drain Water from debris removal area.	Clogged.	Flooding of structure.	Inspection.	
Sludge Removal Pump 12113009	Remove sludge from wash area.	Loss of sludge removal.	Buildup of sludge in debris removal area.	Inspection.	Provide standby sludge pump.

Figure I-4. (Continued)

(sheet 4 of 17)

Operation Name: Predisinfect Directly Using Chlorine Feeder

Operation Number: 12121000

Subfunction: Predisinfect Raw Water 12120000 Function: Pretreat Raw Water 12100000 Subsystem: Treat Raw Water 12000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Chlorine Feeder 12121001	Feed chlorine gas directly into pipeline or conduit, or main, or channel.	High water pressure above ≈ 20 psi.	Flooding and failure of feeder to properly diffuse Cl_2.	Pressure monitoring.	Maximum pressure ≈ 20 psi from Cl_2 bottle.
		Inadequate mixing with water.	Incomplete disinfection.	Water analysis for bacteria and chlorine residual.	Diffuser should be within 25 ft of feeder ahead of pump, valves, or similar equipment.
		Insufficient feed rate for water quantity.	Inadequate disinfection.	Water analysis for bacteria and chlorine residual.	Maximum feed rate is about 75 lb per 24 hours to a pipeline or main and about 300 lb per 24 hours to an open tank or channel.
		Freeze-up due to rapid evaporation.	Loss of chlorination.	Feed indicator drop in feed rate.	Feed at proper rates depending upon ambient temperatures.
		Loss of chlorine residual or increase in chlorine demand.	Possible contamination of water has occured.	Monitor chlorine residual.	The presence of chlorine residual indicates safe water.
Chlorine Storage Tank and Connection 12121002	Same as 12123002				

Note: (1) Direct feed chlorine equipment should be considered as emergency equipment and for small installations where a suitable supply of water is unavailable for operation of solution feeders.

(2) Safety equipment and emergency procedures should be available where chlorine storage and equipment are installed so that hazards to personnel are minimized.

(3) Records should be maintained showing:
- (a) Amount of water treated each 24-hour period (rate & flow)
- (b) Chlorine used (weight)
- (c) Applied dosage
- (d) Chlorinator settings
- (e) Time and location of sampling and results of testing for chlorine residual.

Figure I-4. (Continued)

(sheet 5 of 17)

Operation Name: Predisinfect Raw Water With Chlorine Gas Solution Feeder

Operation Number: 12122000

Subfunction: Predisinfect Raw Water 12120000 Function: Pretreat Raw Water 12100000 Subsystem: Treat Raw Water 12000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Chlorine Solution Feeder 12122001	Feed chlorine in concentrated solution with water into pipe, main, conduit, channel, or tank.	Loss of water pressure.	Loss of vacuum and chlorine feed.	Loss of chlorine flow. Loss of disinfection.	An injector water supply is needed of 25 to 300 psi.
		Loss of power.	Loss of chlorine feeder.	Loss of chlorine flow. Loss of disinfection.	Electric power needed to operate feeder and other accessories.
		Hazardous manifolding of tanks to obtain desired feed rate.	Personnel hazard and danger to losing supply because of large number of tanks required.	Inspection.	Solution feeders can feed up to 8000 lb per 24 hr but discharge rate is determined by tank pressures and capacities. Solution feeders generally are coupled to chlorine evaporators when required for chlorine exceed about 2000 to 3000 lb per 24 hr (see 12123000).
		Freeze-up (reliquefaction).	Flow loss.	Monitor flow and alarms.	
		Proper feed rate.	Inadequate dosage. Over-dosage giving taste from chloramines.	Monitor chlorine residual and combined total chlorine.	
Chlorine Storage Tank and Connections 12122002	Same as 12123002				

See Note (2) Under 12121000.

Figure I-4. (Continued)

(sheet 6 of 17)

Operation Name: Predisinfect Raw Water With Chlorine Feeder Using Evaporator
Operation Number: 12123000
Subfunction: Predisinfect Raw Water 12120000 Function: Pretreat Raw Water 12100000 Subsystem: Treat Raw Water 12000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Chlorinator 12123001	Same as 12122001				
Chlorine Storage Tank and Connections 12123002	Provide chlorine supply on a continuous basis. Scale provide check on tank usage and dosage rates.	Leakage of gas.	Loss of chlorine and a hazard to personnel safety.	Monitor tank weight indicator for unusual loss rate.	More than one source of chlorine is desirable at all times to insure not depleting the tanks connected and spares.
		Intermittent flow when changing tanks.	Loss of disinfection during tank changeover.	Proper mainifold design for chlorine tanks.	
		Freeze-up due to rapid evaporation from tank.	Loss of flow.	Flow indicators register low flow.	
		Insufficient number of tanks for continuous flow.	Loss of disinfection because of lack of chlorine.	Records showing tanks in use and number of spares.	Keep adequate spare tanks on hand (some connected to manifold) at all times (30 day minimum supply).
Chlorine Evaporator 12123003	Provide controlled evaporation of chlorine so that proper mixing with water is achieved. Superheats chlorine gas for high use rates (over 2000 lb per 24 hr).	Loss of power.	Loss of heat source and possible loss of chlorine feed.	Power failure.	An alternate power source or possible steam heat source may be required.
		Reliquefaction of chlorine gas due to pressure.	Improper control of mixing and feed into water.	Drop in chlorine residual. Flow indicator changes on chlorinator. Causes improper chlorinator feed.	A pressure-reducing valve should be installed to prevent reliquefaction.
		Evaporator leak.	Loss of chlorine feed and a hazard to personnel.	Loss of chlorination.	An evaporator should be provided for each chlorinator when used including standby chlorinators.

See Note (2) under 12121000

Figure I-4. (Continued)

(sheet 7 of 17)

Operation Name: Predisinfect With Dry Hypochlorite

Operation Number: 12124000

Subfunction: Predisinfect Raw Water 12120000 Function: Pretreat Raw Water 12100000 Subsystem: Treat Raw Water 12000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Dry Hypochlorite Basket or Bag Feeder Using Hypochlorite Tablets 12124001	Provide container for hypochlorite to gradually dissolve and feed chlorine into water stream.	Basket or bag failure	Loss of feed and chlorination.	Inspection. Water tests.	This is a manual operation requiring personnel monitoring and filling of baskets. Hypochlorite feed is limited to smaller water supply systems.
		Dissolving away of all hypochlorite.	Loss of disinfection.	Water test; frequent refilling of basket/bag.	
Hypochlorite Storage 12124002	Provide excess capacity for feeder.	Absorption of moisture and fire hazard.	Loss of chlorine and possible fire.	Moisture content in storage area.	Hypochlorites are hygroscopic (slightly).
		Corrosion of tank.	Deterioration and loss of storage capacity.	Inspection and preventive maintenance.	Use corrosion resistant materials.

Figure I-4. (Continued)

(sheet 8 of 17)

Operation Name: Predisinfect With Hypochlorite Solution Feeder

Operation Number: 12125000

Subfunction: Predisinfect Raw Water 12120000 Function: Pretreat Raw Water 12100000 Subsystem: Treat Raw Water 12000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Hypochlorite Storage Tank 12125001	Same as 12124002				
Solution Preparation Tank 12125002	Same as 12124002				
Agitator 12125003	Mix hypochlorite solution and maintain solution form.	Power loss.	Loss of mixer.	Power failure.	
		Breakage due to deterioration.	Loss of mixer.	Inspection and preventive maintenance.	
Solution Feeder 12125004	Proportional feed hypochlorite solution into water.	Power loss.	Loss of disinfection.	Power loss.	Power may be electric, mechanical (shaft), water power, pheumatic, or auxiliary (gas engine).
		Feeder failure.	Loss of disinfection.	Inspection and water tests.	Hypochlorites are corrosive and materials must be chosen accordingly.

Figure I-4. (Continued)

(sheet 9 of 17)

Operation Name: Predisinfect With Chlorine Dioxide

Operation Number: 12126000

Subfunction: Predisinfect Raw Water 12120000 Function: Pretreat Raw Water 12100000 Subsystem: Treat Raw Water 12000000

Component & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Sodium Chlorite Storage Tank 12126001	Same as 12124002				Sodium chlorite is explosive creating storage and handling problem.
Ceramic Packed Glass Chlorine Dioxide Generator 12126002	Mix chlorine solution with sodium chlorite and generate chlorine dioxide.	Improper mixing.	Decrease in generation of chlorine dioxide and loss of disinfection.	Water tests. Monitoring Operation of generator.	
Chlorine Solution Feeder 12126003	Feed 500 ppm chlorine solution to generator.	Same as 12122001			
Chlorine dioxide Feeder 12126004	Feed chlorine dioxide to raw water through diffuser.	Same as 12122001			This treatment is good for removing phenols because of high reaction rates.

See Note (2) under 12121000

Figure I-4. (Continued)

(sheet 10 of 17)

Item Name: Pretreat Raw Water - Function

Item Number: 12100000

12130000 Plain Settle Raw Water

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Plain Settle Raw Water 12130000	Reduce heavy sediment loads prior to subsequent treatment processes such as coagulation.	Design and installation such that flow is too fast, turbulent, or length of settling basin too short to allow proper settling.	Overloading of subsequent treatment processes with heavy sediment loads.	Flow rate measurement through basin. Look for turbulent flow. Samples show heavy sediment content in effluent.	Allow sufficient space between influent, even flow (settling), and effluent sections of basin.
		Operating at too high flow rates to achieve settling.	Same.	Same.	It is better to have redundant basins so that peak loads will not exceed settling rates. This also facilitates cleaning and maintenance.
		Algae growth in basin or reservoir.	Taste and odor problems are created.	Visual plus testing.	

Figure I-4. (Continued)

(sheet 11 of 17)

Item Name: Pretreat Raw Water - Function

Item Number: 12100000

12140000 Aerate Raw Water

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Aerate Raw Water-Subfunction 12140000	Reduce CO_2. Reduce taste and odor producing substances, remove substances that interfere with subsequent treatment processes. Oxidize iron manganese, hydrogen sulfide, and organic matter.	Equipment failure. Short circuit of water flow around aeration process.	Increased corrosiveness. Loss of function and exceed water quality criteria.	Water test. Proper design. Inspection and prevention of channel failure	No common wall boundaries or direct overflow to finished water.
		Contamination from airborne matter.	Contamination of water supply.	Proper design. Cover over process. Use filtered supply.	
		Excessive aeration may cause adverse effects on iron and manganese removal if low pH is created.	Loss of function if removing iron and manganese.	Dissolved oxygen content analysis of water.	Chlorinate prior to aeration to aid oxidation; however this creates loss of chlorine and increases costs.
		Increased dissolved oxygen content in water.	Increased corrosion.	Dissolved oxygen content analysis of water.	
		Overload process either because of failure, degradation or peak demand. Loss of oxygen contact time.	Loss of function due to overload.	Monitor demand and load on system.	Provide standby redundant equipment in order to meet overloads, shutdown for maintenance or repair.

Figure I-4. (Continued)

(sheet 12 of 17)

Item Name: Soften Water

Item Number: 12210000

Treat Water 12200000, Treat Raw Water 12000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Lime-Soda-Ash Softening 12211000	Add CaO to remove CO_2 as $CaCO_3$ and to oxidize and precipitate iron and manganese in raw water Operation involves lime feed, rapid mix, flocculation, sludge removal (rapid sand filtration and stabilization would follow).	Trace elements in lime.	Water contamination.	Analysis of lime to check quality.	
		Lime feeder clogged.	Loss of lime feed. Failure of operation.	Periodically inspect and clean lime feed equipment.	
		Sludge removal equipment failure.	Loss of operation.	Loss of equipment operation.	
		Improper floc mix and formation.	Decreased sedimentation effectiveness and increased clogging of filter.	Visual inspection can confirm proper floc formation. Jar tests should be performed for proper chemical dosage.	Use turbidimeter to check variance in raw water turbidity, then perform jar tests and correlate to determine proper chemical dosage control.
Ion Exchange 12212000	Remove $CaCO_3$ and other ions by displacement.	Clogging.	Frequent flushing requiring more off-line (down) time.	Increase in loss of head across resin bed.	A standby unit is required for operation during regeneration.

Figure I-4. (Continued)

(sheet 13 of 17)

Item Name: Coagulate, Flocculate, and Sediment

Item Number: 12220000

Treat Water 12200000, Treat Raw Water 12000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Add chemicals and Rapid Mix 12221000	Attain full mixing and contact of suspended solids with flocculant agent.	Flocculent feeder failure.	Failure of operation.	Alarm; inspection of feeder.	Standby feeder necessary for continuous operation.
		Baffled mixing basin having wide flow variations.	Not suitable for mixing. Reduced efficiency.	Flow measurement.	Baffled basins not suitable where flow varies widely.
		Mechanical mixer failure.	Loss of operation.	Inspection.	Install over capacity so that standby mixing capacity is available.
		Excess alum.	Destroys floc and carries into finished water.	Monitor aluminum content in finished water. Perform jar tests and monitor turbidity to control alum dosage rate.	
Coagulate and Flocculate 12222000	Attain complete envelopment of suspended particles within floc.	Flocculator failure.	Loss of agitation and coalescence of particles.	Visual inspection. A proper floc can be seen in the water.	Paddle wheel flocculators are used for agitation.
		Baffle failure.	Velocity flow occurs which shears floc and prevents coalescence.	Visual inspection. A proper floc can be seen in the water.	Care must be taken in design to prevent this.
Sedimentation 12223000	Reduce amount of settleable solids.	Flow control.	Insufficient time for settling.	Flow monitoring.	
		Sludge removal equipment failure.	Shutdown of basin for cleaning.	Operations; visual inspection.	Standby equipment is required in order to remove a basin from service.
		Sludge accumulation.	Take basin out of service for cleaning.	Measure sludge depth.	

Figure I-42 (Continued)

(sheet 14 of 17)

Item Name: Filter Water

Item Number: 12230000

Treat Water 12200000, Treat Raw Water 12000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Gravity Filter 12231000	Separate suspended and colloidal impurities from water by passing through a porous medium.	Clogging.	More frequent backwashing.	High loss of head through filter.	
		Breakthrough.	Failure and passage of contaminated water.	Loss in head. Increased alum in water and increased chlorine demand.	Standby filter capacity is necessary to provide redundancy for removing a filter from service.
		Media disruption due to high backwash rate.	Disruption of filter bed and filter must be removed from service and restored.	Media dislodgement during backwash. Care must be exercised when backwashing. Could lead to breakthrough.	
		Controls failure such as control of flow (flow controlled).	Filter must be removed from service until controls restored.	Operation of filter. Loss of head.	
		Filter breakthrough at corners.	Loss of filtration.	Buildup of floc or surface coating in corners of filter.	Media should be periodically removed, underdrains cleaned, and media restored.
Pressure Filter 12232000	Same as 12231000 above				

Notes: Filtration is probably the single most important process in treating water sources of poor quality. When coupled with pretreatment, filtration removes over 99 percent of bacteria (post chlorination controls remainder); over 98 percent of polio virus removed by flocculation and filtration, turbidity reduced to less than 0.2 Jackson Units by filtration; color iron, manganese are easily removed with proper pretreatment; large microorganisms readily removed.

Figure I-4. (Continued)

(sheet 15 of 17)

Item Name: Post Disinfect Water

Item Number: 12230000

Treat Water 12200000, Treat Raw Water 12000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
12241000 through 12246000	Same as 12121000 through 12126000				

Figure I-42 (Continued)

(sheet 16 of 17)

Item Name: Provide Special Treatment

Item Number: 12300000

Treat Raw Water 12000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Dechlorinate Water 12311000	Remove excess chlorine following treatment having super chlorination to render the water more palatable. Methods include adding SO_2, aeration, treatment using activated carbon.	Failure of treatment.	Super chlorinated water enters distribution system. It can irritate eyes and be unpalatable.	Monitor treatment process. Test finished water. Monitor Cl_2 residual.	
		Overdosage.	Reduced (or loss) chlorine residual.	Monitor chlorine residual.	
Ozonate Water 12312000	Diffuse in water to disinfect.	Loss of ozone generating equipment due to failure or to power loss.	Loss of disinfection.	Alarm should be provided. Test water.	
Treat with Carbon 12321000	Add activated carbon to remove tastes and odors, phenolic compounds, toxic chemicals excess chlorine.	Failure of feed equipment.	Loss of control. Possible contamination of water.	Alarm and monitoring system. Test water.	
Add Fluoride to Water 12331000	Additive to fight tooth decay.	Fluoride below or above limits deleterious to dental health due to flow proportioner failure.	Exceed limits causing dental deterioration.	Alarm and monitoring system. Test water Colorimetric tests.	

Notes: Records should be maintained for all chemical additions:

(a) Flow and volume of water treated
(b) Amount of chemical used
(c) Theoretical dosage
(d) Machine setting and actual dosage
(e) Chemicals on hand and ready for use
(f) Concentration of chemicals

Figure I-4. (Continued)

(sheet 17 of 17)

Item Name: Treat Raw Water

Item Number: 12000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Special Considerations 12000000	Design.	Failure of common walls where higher quality water could be contaminated by lower quality water.	Contamination of water.	Visual examination Proper design should preclude occurence.	High quality water should be above lower quality water where common divisions occur.
				Increased chlorine demand or loss of residual.	Common walls should not be allowed in proper design.
		Bypass of treatment plant.	Loss of treatment, possible distribution of contaminated water.	Visual examination. Loss of chlorine residual.	Proper design and maintenance should preclude existence in plants where raw water must be treated to meet standards.
		Treatment facilities contaminated by airborne pollutants.	Water contamination.	Air monitoring. Increased chlorine demand or loss of residual.	Proper design should have covered facilities.
		Sanitary (toilets, etc.) equipment failure.	Water contamination.	Visual inspection. Increased chlorine demand or loss of residual.	Proper design should isolate sanitary equipment from treatment processes and water so that failure would not cause contamination of water.
		Piping failure of low quality water.	Water contamination if low quality main could fail and damage higher quality main or dump water into higher quality water.	Visual inspection. Loss of chlorine residual.	If low quality and high quality mains must be routed through same area, route high quality above low quality with maximum separation. Never route low quality water over higher quality water.

Figure I-4. (Continued)

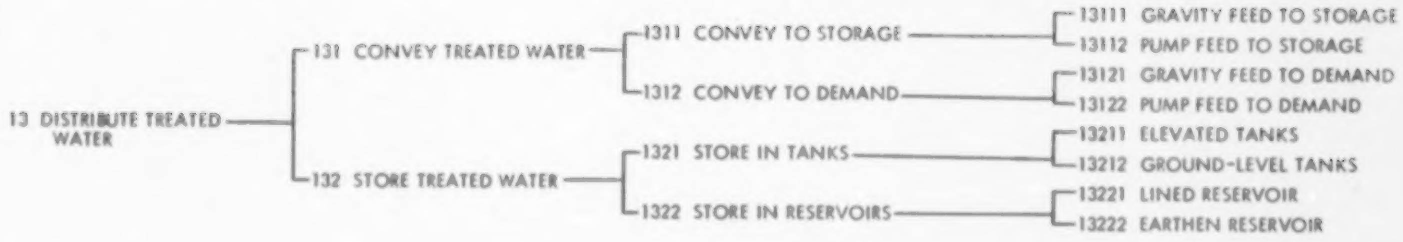
13 DISTRIBUTE TREATED WATER
131 CONVEY TREATED WATER
132 STORE TREATED WATER
1311 CONVEY TO STORAGE
1312 CONVEY TO DEMAND
1321 STORE IN TANKS
1322 STORE IN RESERVOIRS
13111 GRAVITY FEED TO STORAGE
13112 PUMP FEED TO STORAGE
13121 GRAVITY FEED TO DEMAND
13122 PUMP FEED TO DEMAND
13211 ELEVATED TANKS
13212 GROUND-LEVEL TANKS
13221 LINED RESERVOIR
13222 EARTHEN RESERVOIR

Figure I-5.. Structure and Matrix for Distribution of Treated Water, Subsystem 13

(sheet 1 of 6)

Item Name: Distribute Treated Water

Item Number: 13000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Convey Treated Water to Storage by Gravity 13111000	Transport treated water to storage under gravitational force to maintain pressure.	Conduit or pipe leakage or failure. Valve failure. Draft such as fire pump causing loss of pressure.	Inflow of contaminated water.	Inspection and pressure testing of conduit or pipe. Excess leakage should not be allowed.	Proper design should not have treated water passing below lower quality water or in adjacent walls where contamination might flow into finished water if failure occurred. Sewers to be 10 away. Repairs should have flushing and disinfection procedures to prevent contamination. Use proper materials. Do not use materials that support the growth of pathogenic organisms. Materials should meet AWWA specs.
			Loss of control. Possible contamination during repair. Also, backflow could occur if check valve failed.	Periodically check valves for proper operation.	
		Sludge in pipe or conduit from settling of solids out of water.	Loss of flow.	Inspection.	Periodic flushing necessary to remove settled sludge.
		Contamination or slime in pipe or conduit.	Bacterial contamination, odors, and tastes.	Monitor chlorine residual. Test water.	Provide chlorine residual in water. Minimum is 4 mg/ℓ for 30 min.
		Flooding.	Contamination.	Pipe or conduit should be installed above flood levels to prevent backflow.	Proper design should have excess pressure in pipe or conduit to prevent flooding and back flow.
		Corrosion.	Equipment failure, added metal content to water (may contaminate).	Monitoring pH, alkalinity, and inspection results. Test water.	Proper material selection, proper pH and control of alkalinity should prevent. Prevent the occurrence of dead water pockets.

Figure I-6. Failure Modes and Effects Analysis

(sheet 2 of 6)

Item Name: Distribute Treated Water

Item Number: 13000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Pump Treated Water to Storage 13112000	Pump water to achieve head required to reach storage head and supply water.	All in 13111000			
		Pump failure.	Loss of pressure.	Alarm. Monitoring operation.	Sufficient standby pump capacity should be provided.
		Controls failure to turn pump on at low storage.	Loss of pressure.	Alarm. Monitoring operation.	Sufficient displays should be provided for monitoring the operation.
Convey to Demand by Gravity 13121000	Furnish water by gravity using storage head to maintain pressure.	All shown in 13111000 Note: The rate of failure of distribution mains depends upon length of installed pipe.			
		Backflow in low pressure area.	Contamination of supply.	Cross-connection survey program and pressure test programs for minimizing the chance of backflow and low pressure occurrence.	Proper system design should preclude low pressure which might suck (or siphon) contamination into distribution system. This use of vacuum breakers at consumer connections, back pressure valves, and check valves would lessen chances of occurrence.
		Dead ends.	Stagnation and contamination of supply.	A flushing procedure should be followed to periodically flush dead ends and test water quality.	

(Continued)

Figure I-6. (Continued)

(sheet 3 of 6)

Item Name: Distribute Treated Water
Item Number: 13000000

<table>
<tr><th>Item Name & Number</th><th>Component Function</th><th>Failure Mode</th><th>Failure Effect</th><th>Detection Means</th><th>Remarks</th></tr>
<tr><td>13121000 (Continued)</td><td></td><td>Clogging.</td><td>Loss of capacity and higher susceptibility to low pressure occurrence.</td><td>Increased head pressure in a main.
Loss of pressure.</td><td>Proper chemical controls and flushing program should be followed.</td></tr>
<tr><td colspan="6">Note: (1) A plumbing code should prohibit connections which might allow discharge or suction of unknown or questionable liquids into the water supply. Blow-off connections to sewers or sewer manholes should be prohibited.
(2) A system should be provided with sufficient bypass and blow-off valves to make necessary repairs without undue interruption of service over any appreciable area.</td></tr>
<tr><td>Pump Water to Demand 13122000</td><td>Pump water to achieve head and volume to supply demands.</td><td colspan="4">All in 13121000
Note: (1) A plumbing code should prohibit connections which might allow discharge or suction of unknown or questionable liquids into the water supply. Blow-off connections to sewers or sewer manholes should be prohibited.
The rate of failure of distribution mains depends upon the length of installed pipe.</td></tr>
<tr><td></td><td></td><td>Pump failure.</td><td>Loss of pressure and capacity.</td><td>Alarm. Monitoring operation.</td><td>Sufficient standby pump capacity should be provided.</td></tr>
<tr><td></td><td></td><td>Controls failure to turn pump on to meet demand.</td><td>Loss of pressure and capacity.</td><td>Alarm. Monitoring operation.</td><td>Sufficient display information provides operator with monitoring instrumentation to display problem occurrence.</td></tr>
<tr><td></td><td></td><td>(Continued)</td><td></td><td></td><td></td></tr>
</table>

Figure I-6. (Continued)

(sheet 4 of 6)

Item Name: Distribute Treated Water

Item Number: 13000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
13122000 (Continued)		Backflow in low pressure area.	Possible contamination of supply.	Cross-connection survey program and pressure test programs for minimizing the chance of backflow and low pressure occurrence.	Proper system design should preclude low pressure which might suck (or siphon) contamination into the distribution system. The use of vacuum breakers at consumer connections, back pressure valves, and check valves would lessen chances of occurrence.
		Dead ends.	Same as 13121000.		
		Clogging.	Same as 13121000.		
Store Treated Water in Elevated Tanks 13211000	Provide storage capacity for treated water at sufficient height to provide head sufficient to maintain system pressure at 20 psi minimum.	Tank rupture (freezing of riser or failure)	Loss of water.	Inspection and testing.	Proper inspection prevents rupture. Means to prevent freezing should be installed where freezing temperatures of sufficient lowness and duration occur.
		Corrosion.	Contamination of water by corrosion products.	Control pH, dissolved oxygen, monitor inspection results. Test water.	Proper material selection, proper construction, proper maintenance, proper controls will prevent failure. A periodic tank cleaning and coating is required.

Figure I-6. (Continued)

(sheet 5 of 6)

Item Name: Distribute treated water

Item Number: 13000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
13211000 (Continued)		Level controls failure.	Maintain improper tank level control. Possible loss of reserve (excess) water storage.	Compare head pressure and level control actuation points. Periodically inspect controls and calibrate.	Level controls are usually connected to controller for pump that fills tank.
		Bacteria in water.	Contamination of water.	Water tests for bacteria and chlorine residual.	Booster chlorination is required where bacteria occur in stored finished water. Chlorine residual is 0.4 mg/ℓ for 30 min minimum.
Store Treated Water in Ground Level Tanks 13212000	Same as 13211000				
Store Treated Water in Lined Reservoir 13221000	Provide storage capacity for treated water at sufficient head to maintain system pressure at 20 psi minimum.	Reservoir rupture.	Loss of water.	Inspection and testing.	
		Bacteria in water.	Water contamination.	Test water for bacteria and chlorine residual. Note (1) below	Booster chlorination may be required. Chlorine residual should be 0.4 mg/ℓ for 30 min minimum. Reservoir should be covered.
	Note: A good maintenance program is required for clearwells and other lined reservoirs for finished water.	Level controls failure.	Possible loss of water.	Compare head, pressure, and level control actuation points. Periodically inspect controls and calibrate.	Level controls are usually connected to controller for pump that fills reservoir.
		Contamination.	Water failure. Note (2)	No sewer within 50 feet with a below-ground floor. Ten feet all others.	

Figure I-6. (Continued)

(sheet 6 of 6)

Item Name: Distribute Treated Water

Item Number: 13000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
13221000 (Continued)		Slime or sediment in reservoir.	Tastes and odor.	Visual inspection.	Chlorine residual should minimize occurrence. Periodic cleaning is required.
Store Treated Water in Earthen Reservoir 13222000	Same as 13221000 above plus:	Aquatic vegetation growth.	Taste and odors.	Visual inspection.	Chlorine residual should minimize. Periodic treatment with copper sulfate and cleaning is required.

Note: (1) Open finished water reservoirs should not be permitted. In event they are used, chlorine residuals must be maintained or booster chlorination facilities are required to insure complete disinfection before distribution to the first customer.

(2) The surface should be graded to drain surface water away from the reservoir and the area should be secured from public or animal access by fencing. Manholes should be elevated and have a watertight cover. Vents should be inverted and screened (No. 24 mesh) to prevent rain, insects, or animals from entering.

General notes for distribution subsystems:

Bacteriological quality hazards
- a. Insufficient treatment at point of production
- b. Cross-connections
- c. Improperly protected distribution system storage
- d. Inadequate disinfection of mains
- e. Unsatisfactory construction of mains, including improper joint-packing material
- f. Close proximity of sewer and water mains
- g. Improperly constructed, maintained, or located blow-off, vacuum, and air relief valves
- h. Negative pressures in the distribution system
- i. Dead ends in distribution mains

Figure I-6: (Continued)

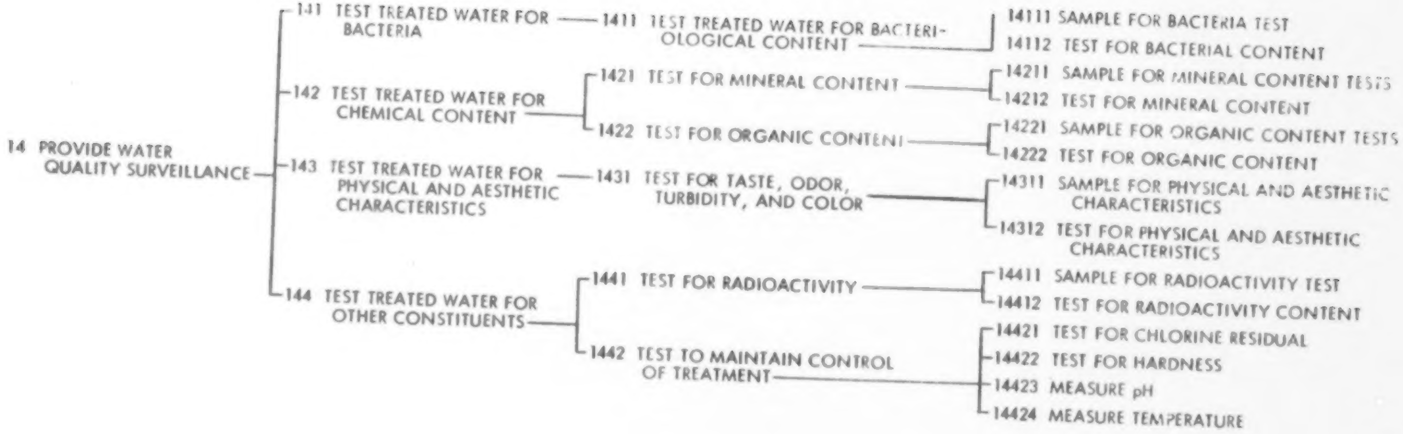
14 PROVIDE WATER QUALITY SURVEILLANCE
141 TEST TREATED WATER FOR BACTERIA
142 TEST TREATED WATER FOR CHEMICAL CONTENT
143 TEST TREATED WATER FOR PHYSICAL AND AESTHETIC CHARACTERISTICS
144 TEST TREATED WATER FOR OTHER CONSTITUENTS
1411 TEST TREATED WATER FOR BACTERIOLOGICAL CONTENT
1421 TEST FOR MINERAL CONTENT
1422 TEST FOR ORGANIC CONTENT
1431 TEST FOR TASTE, ODOR, TURBIDITY, AND COLOR
1441 TEST FOR RADIOACTIVITY
1442 TEST TO MAINTAIN CONTROL OF TREATMENT
14111 SAMPLE FOR BACTERIA TEST
14112 TEST FOR BACTERIAL CONTENT
14211 SAMPLE FOR MINERAL CONTENT TESTS
14212 TEST FOR MINERAL CONTENT
14221 SAMPLE FOR ORGANIC CONTENT TESTS
14222 TEST FOR ORGANIC CONTENT
14311 SAMPLE FOR PHYSICAL AND AESTHETIC CHARACTERISTICS
14312 TEST FOR PHYSICAL AND AESTHETIC CHARACTERISTICS
14411 SAMPLE FOR RADIOACTIVITY TEST
14412 TEST FOR RADIOACTIVITY CONTENT
14421 TEST FOR CHLORINE RESIDUAL
14422 TEST FOR HARDNESS
14423 MEASURE pH
14424 MEASURE TEMPERATURE

Figure I-7.. Structure and Matrix of the Water Quality Surveillance Subsystem

(sheet 1 of 2)

Item Name: Provide Water Quality Surveillance

Item Number: 14000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Sample for Bacteria Test 14111000	Provide adequate sampling to statistically provide assurance of not exceeding drinking water standards in the entire distribution system.	Samples taken too close to treatment.	Entire distribution system not covered meaning far points in system may not meet bacteriological limits.	Independent survey of sampling by Public Health Service or other service organizations.	
		Sampling container not properly cleaned, sample insufficiently protected, sample not tested as soon as possible.	Contamination of sample resulting in erroneous analytical results.	Comparison of sample results with previous test results and re-sample for retesting.	
		Insufficient number of samples per month. Lack of random sampling and good coverage of system.	Possibility that statistical assurance of good quality cannot be made. Also, PHS requirements are not met.	Monitor sampling to insure correct number are taken. Check population frequently to insure correct number specified.	If bacteria are found in water in varying numbers, it becomes very important to assure meeting requirements.
Test for Bacteria Content in Samples 14112000	Perform test for bacteria in accordance with standard methods. Laboratory should be certified.	Test procedures which are not as rigorous as standard methods.	Possible nonidentification of bacteria when water is contaminated.	Survey of laboratory procedures, media, other chemicals, and comparison with standard methods.	Laboratory should be certified.
Sample and Test Water for Chemical (Mineral & Organic) Content 14200000	Test water at sufficient intervals to ensure meeting the drinking water standards.	Insufficient sampling and testing to statistically ensure water quality.	Possible water contamination.	Statistical analysis of all test results.	Each test result should be compared with previous results to see if quality is deteriorating.
		Sampling and testing not in accordance with standard methods.	Possible erroneous results.	Survey of laboratory methods and procedures.	Laboratory should be certified.

Figure I-8. Failure Modes and Effects Analysis

(sheet 2 of 2)

Item Name: Provide Water Quality Surveillance

Item Number: 14000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Test Water for Physical and Aesthetic Properties 14300000	Test for turbidity, taste, odor, and color.	Insufficient sampling and testing to statistically ensure water quality.	Possible water contamination.	Statistical analysis of all test results.	Instruments are available for continuous monitoring of turbidity.
Test for Other Constituents 14400000	Test for radioactivity.	Insufficient sampling and testing to statistically ensure water quality.	Possible water contamination.	Statistical analysis of all test results.	Instruments are available to measure radioactivity.
	Test to maintain control of treatment and distribution.	Failure to adjust treatment to meet variations in raw water; failure to monitor treatment to ensure all processes are functioning properly from raw water intake to the farthest point in the distribution.	Inadequate treatment, inefficient treatment, contamination by overtreating.	Operational control tests are for: alkalinity, aluminum chloride, chlorine residual, color, fluoride, hardness, iron, jar tests, manganese, pH, taste and odor, turbidity.	Frequency of tests should be such to assure proper treatment of water as its quality varies and to ensure proper control of the water system.

Figure I-8. (Continued)

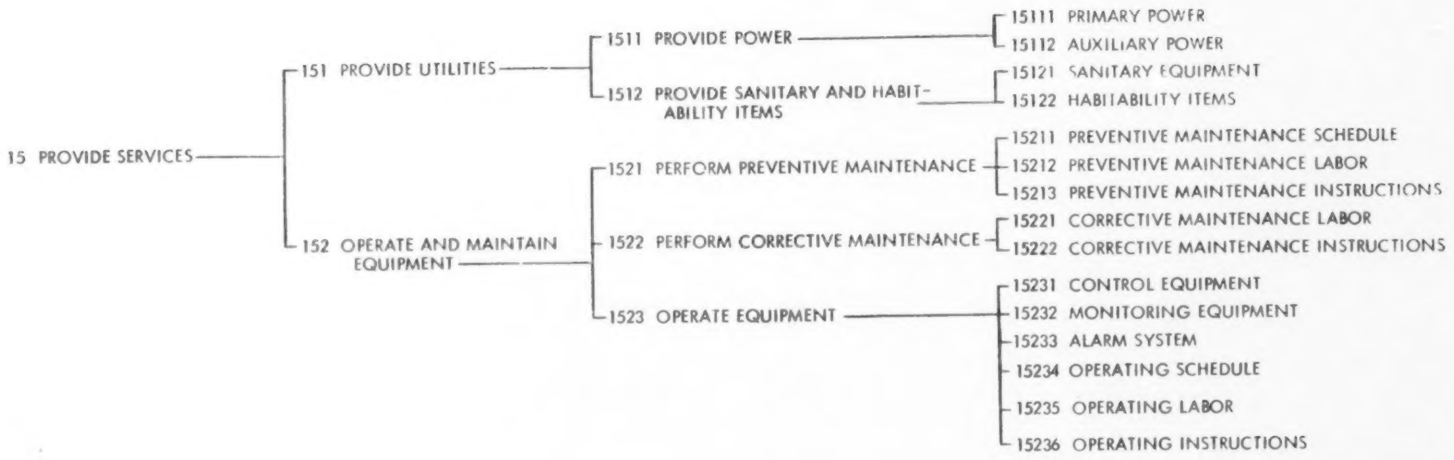
15 PROVIDE SERVICES
151 PROVIDE UTILITIES
1511 PROVIDE POWER
15111 PRIMARY POWER
15112 AUXILIARY POWER
1512 PROVIDE SANITARY AND HABITABILITY ITEMS
15121 SANITARY EQUIPMENT
15122 HABITABILITY ITEMS
152 OPERATE AND MAINTAIN EQUIPMENT
1521 PERFORM PREVENTIVE MAINTENANCE
15211 PREVENTIVE MAINTENANCE SCHEDULE
15212 PREVENTIVE MAINTENANCE LABOR
15213 PREVENTIVE MAINTENANCE INSTRUCTIONS
1522 PERFORM CORRECTIVE MAINTENANCE
15221 CORRECTIVE MAINTENANCE LABOR
15222 CORRECTIVE MAINTENANCE INSTRUCTIONS
1523 OPERATE EQUIPMENT
15231 CONTROL EQUIPMENT
15232 MONITORING EQUIPMENT
15233 ALARM SYSTEM
15234 OPERATING SCHEDULE
15235 OPERATING LABOR
15236 OPERATING INSTRUCTIONS

Figure I-9. Structure and Matrix of Services Subsystem

(sheet 1 of 6)

Item Name: Provide Utilities

Item Number: 15100000

Provide Services 15000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Provide Power 15110000	Supply primary electrical power.	Power loss unless secondary or auxiliary power supply is provided.	Loss of electrical equipment.	None for power failures. Interruptions for service maintenance can be forecast.	
	Supply auxiliary electrical power.	Power loss of primary and auxiliary power sources.	Loss of electrical equipment.	None for power failures. Interruptions for service maintenance can be forecast.	

Figure I-10. Failure Modes and Effects Analysis

(sheet 2 of 6)

Item Name: Provide Sanitary and Habitability Items

Item Number: 15120000

Provide Utilities 1510000, Provide Services 15000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Sanitary Equipment 151210000	Provide facilities for disposing waste and sewage for personnel and operations such as laboratories, cleaning operations, drains.	Overflowing or pipe failure.	Contamination of water unless located so as to prevent contamination.	Inspection to check flow paths and distance removed from system operations.	Proper design dictates that sanitary facilities be designed so that failures will not cause water contamination.
Human Engineering 15122000	Provide work environments which foster effective procedures, work patterns, and personnel safety and which minimize discomfort, distraction, and any other factors which degrade human performance or increase error. The design should minimize personnel and training requirements within limits of time, costs, and performance trade-offs.	Conditions hindering human performance.	Inefficient operation and possible safety hazards.	Inspection of facilities to assure space and environment suitable for man to work in. Standardization of controls, labeling, and arrangement are common functions to look for. Alarm systems. Fail-safe devices for hazardous operations. Location and arrangement suitable for man to work in to maintain the system.	Many subjective attributes can be used to measure the human engineering aspects of a system: clearances, location of controls within easy reach and with room to operate, standard controls, safety devices, alarms, fail-safe devices, etc.

Figure I-10.(Continued)

Item Name: Perform Preventive Maintenance

Item Number: 15210000

Operate and Maintain Equipment 15200000, Provide Services 15000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Schedule 15211000	Provide a checklist for guiding, planning, and following the performance of maintenance designed to prevent equipment failure and enhance efficient system operation.	No schedule or records to provide check of maintenance performed.	Possible neglect to perform all maintenance which should be done resulting in higher probabilities of system degradation and failure.	Check for schedule and record keeping to ensure all maintenance is being performed.	This is subjective since the adequacy of a preventive maintenance program must also be examined.
Labor 15212000	Personnel to perform preventive maintenance tasks. This may be determined by the makeup of plant equipment and the requirements for maintaining equipment.	Lack of training and experience with equipment. Lack of certification.	Possibility of poor maintenance and induced equipment failures.	Check length of experience of maintenance personnel, amount of training received, and skill levels achieved.	The skill titles may be those listed in the U.S. Department of Labor Dictionary of Occupational Titles.
Instructions 15213000	Provide easy to read step by step procedures for performing maintenance in a form usable and available to personnel. The instructions should state personnel skill levels required to perform the maintenance tasks.	Instructions not available, not easy to follow, not easily handled when performing maintenance.	Possible neglect to perform maintenance in correct manner leading to higher probability of system degradation and failure. The possibility of creating safety hazards exists.	Check for availability of instructions, intelligibility, and ease of using when performing maintenance. Are equipment manuals available?	

Figure I-10.(Continued)

(sheet 4 of 6)

Item Name: Perform Corrective Maintenance

Item Number: 15220000

Operate and Maintain Equipment 15200000, Provide Services 15000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Labor 15221000	Personnel to perform corrective maintenance. This may be determined by the makeup of plant equipment, probability of failure, and equipment complexity.	Lack of training, experience, or skills to perform maintenance. Lack of certification.	Possibility of poor maintenance leading to recurring and induced equipment failure.	Check experience and skill levels of personnel. Are they sent to training schools? What amount of training received and skill levels achieved?	The skill titles may be those used in the U. S. Department of Labor Dictionary of Occupational Titles.
Instructions 15222000	Same as 15213000				

Figure I-10 (Continued)

(sheet 5 of 6)

Item Name: Operate Equipment

Item Number: 15230000

Operate and Maintain Equipment 15200000, Provide Services 15000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Control Equipment 15231000	Provide control system motive power (pneumatic, hydraulic, electrical).	Failure of control of motive power.	Failure of remote controls, manual control becomes necessary.	Alarms.	Control systems should have redundancies built in for high failure rate equipment.
Monitoring Equipment 15232000	Provide control and monitoring displays for operating the system: dial indicators, recorders, lights, meters, gages, etc.	Failure of instrumentation may cause operator to make a control error.	Maloperation of system; loss in water treatment capacity.	Comparative instrumentation to check instrument performance.	Operating instructions should provide for procedures to compare various process readings which would provide check on instrument performance.
Alarm System 15233000	Provide alarms for critical and hazardous operations to alert operators to occurrence of failure or hazard. Such areas include chlorine room monitoring, Cl_2 tank weight, fluoride monitoring, tank levels, power source, fire, etc.	Lack of alarms.	Hazards to water contamination and to personnel safety.	Inspection of system to determine hazardous areas and presence or absence of alarms.	
Operating Schedule 15234000	Provide sequence of operation of system (e.g., minimum load, avg load, full capacity), rotation of equipment, correlation to preventive maintenance requirements.	Lack of schedule.	Operation of system in an inefficient manner or possible early degradation of portion of system due to over-operation and under-maintenance.	Does schedule exist? Are records kept?	Proper sequential operation and rotation of equipment leads to equipment longevity.

Figure I-10 (Continued)

(sheet 6 of 6)

Item Name: Operate Equipment

Item Number: 15230000

Operate and Maintain Equipment 15200000, Provide Services 15000000

Item Name & Number	Component Function	Failure Mode	Failure Effect	Detection Means	Remarks
Operating Labor 15235000	Personnel to operate system. Determine by system design and requirements in emergencies.	Lack of training, experience, skills, or certification of operators.	Possible maloperation of system. Possible poor operation leading to early wearout and induced equipment failure.	Check experience, skills, certification. Are operators sent to specialized training? What training and experience achieved?	The skill titles may be those used by the U.S. Department of Labor Dictionary of Occupational Titles. An evaluation of plant operation in relation to operator training and experience may be required to rate this.
Operating Instructions 15236000	Provide easy to read step by step procedures for operating the system in all operating modes from low capacity to full capacity and emergency control.	Instructions not available, not posted, not easily obtained when needed.	Possible failure of water system to meet quality and demand requirements.	Are operating instructions available to operators? Are they simple and straightforward? Are they within the operators watch station? Do they cover all operational modes including emergency procedures?	A qualitative evaluation may be necessary to determine if the instructions are followed if available.

Figure I-10 (Continued)